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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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LABORATORY, EXPOSURE, AND SIMULATED SERVICE TESTS OF SLOW-CURING LIQUID ASPHALTS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by R. H. LEWIS, Associate Chemist

and

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AN INVESTIGATION of the weather-resistant properties of a number of liquid asphalts of the slow-curing type was recently completed by the Bureau of Public Roads in cooperation with Committee 3-b on Cutbacks and Liquid Residuals of the Association of Asphalt Paving Technologists. A general report¹ on this work was given at the January 1936 meeting of the Association.

The data presented in that report were discussed only briefly and data on some phases of the investigation were omitted entirely. It is felt that the work warrants a more detailed discussion and therefore this report, which presents the viewpoint of the Bureau only, has been prepared.

The purpose of the investigation was to determine if the changes that occur in the physical and chemical properties of liquid asphalts present as binders in road-surfacing mixtures of the densely graded type and the behavior of the road mixtures under simulated service conditions could be correlated with the results of conventional laboratory tests on these products and with the results of exposure tests^{2,3} similar to those previously made by the Bureau on liquid asphalts of the same type.

The investigation was carried out along the following lines:

1. The liquid asphaltic materials were examined by the test methods recommended by the Bureau of Public Roads and The Asphalt Institute, and by other test methods that have been or are in use in specifications for liquid asphaltic road materials of the slow-curing type.

2. The asphaltic materials were exposed in comparatively thin films to the action of solar light and heat and of air under different test conditions. The amount of volatile matter lost under these conditions was determined and the residues formed during the various periods of exposure were tested for consistency, ductility, and solubility.

3. Mixtures of the liquid asphalts with a sand and limestone-dust aggregate were made. Portions of these mixtures were molded into specimens for the Hubbard-Field stability test and for the toughness test (resistance to impact). The specimens were tested immediately, and after exposure to various test conditions for different periods of time.

4. The greater portions of these prepared mixtures were placed as wearing surfaces on a small circular track and subjected to weather conditions and con-

trolled traffic of rubber-tired wheels. The behavior of the surfaces was noted and the different sections were cored from time to time to determine the changes in stability of the mixtures.

PHYSICAL AND CHEMICAL PROPERTIES OF ASPHALTIC MATERIALS DIFFERED WIDELY

Slow-curing liquid asphaltic materials of the SC-2 type, similar to those investigated in previous studies by the Bureau, and having Furol viscosities of 250-320 seconds at 122° F., were selected for investigation. Information relative to the source of the base petroleum and the refining process used in the manufacture of the selected materials is as follows:

Sample 1: An uncracked, steam-reduced Mexican residual (probably 250-300 penetration asphalt) blended with gas oil to reduce the viscosity.

Sample 2: An uncracked, steam-reduced midcontinent residual.

Sample 3: An uncracked, steam-reduced California residual.

Sample 4: A 1,000-pound pressure cracking coil residual produced from gas oil.

Sample 5: A low-level residue, reduced from west Texas crude by the Dubbs process, blended with medium-heavy gas oil to reduce the viscosity. The transfer temperature of the Dubbs process was 910° F., chamber pressure 200 pounds, and flashed in a vacuum to approximately 4,000 Furol viscosity at 122° F.

Sample 6: A blend of 50 percent of sample 2 and 50 percent of sample 4.

The data obtained on sample 6 were not included in the report presented by committee 3-b. There was considerable difference of opinion among the members of the committee as to the advisability of including a blend of cracked and uncracked products in this study. It was held that the difference in behavior of uncracked materials, as represented by samples 1, 2, and 3, and of cracked materials, as represented by samples 4 and 5, was of major importance. The behavior of a blend of two materials in only one proportion would not give an accurate picture of the probable behavior of blends of other materials or blends of the same materials in different proportions. The committee therefore agreed that the behavior of blends should be considered in a separate study. The behavior of sample 6 under the various test conditions, however, was of such unusual character that the Bureau believes the data relative to this material should be included in this report.

Results of the laboratory tests on the liquid asphalts, together with the test requirements for SC-2 grade material, are given in table 1. It will be seen from a study of this table that, with the exception of sample 1,

¹ Proceedings of the Technical Sessions of the Association of Asphalt Paving Technologists, Cleveland, Ohio, January 23, 1936.

² A Study of Some Liquid Asphaltic Materials of the Slow-Curing Type, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol. 15, no. 4, June 1934.

³ Further Studies of Liquid Asphaltic Road Materials, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol. 16, no. 6, August 1935.

TABLE 1.—Results of tests on original materials showing conformity with the requirements for the SC-2 grade of liquid asphaltic material

	Sample no.						Requirement for SC-2 grade
	1	2	3	4	5	6	
Specific gravity at 77° F.	0.970	0.942	0.972	1.054	1.010	1.000	
Flash point, °F.	220	500	295	380	270	420	200
Fulcrum viscosity at 122° F., seconds	315	291	312	272	256	283	200-320
Float at 77° F., do.	19	100	23	65	37	61	
Loss at 325° F., 5 hr., 50 g., percent	12.3	0.2	5.7	1.1	5.4	0.7	
Loss at 325° F., 5 hr., 20 g., do.	19.4	0.2	10.7	1.8	9.2	1.1	
Reaction to Oliensis test	Negative	Negative	Negative	Positive	Positive	Positive	
Organic matter insoluble in CS ₂ , percent	0.09	0.04	0.06	0.18	0.38	0.10	
Organic matter insoluble in CCl ₄ , do.	18.3	3.0	5.4	11.2	2.24	0.15	
Organic matter insoluble in 86° B. naphtha, do.	9.0	3.0	3.7	7.2	10.8	5.1	
Asphaltic residue, do.	67.1	72.1	62.6	64.5	74.4	54.6	
Distillation (A. S. T. M. D402-34T):							
Total amount off by volume at 437° F., do.	15.5				1.5		2-
do. at 600° F., do.	25.5	0	11.0	0	15.0	0	15-
do. at 680° F., do.	22.0	0	9.8	0	12.3	0	25-
Distillation loss ² , percent (by weight)	4.7	2.1	5.0	4.6	4.7	3.0	
Total loss in distillation test, do.	26.7	2.1	14.8	4.6	17.0	3.0	
Tests on the distillation residue:							
Float at 122° F., seconds	196	40	41	29	89	29	25-
Organic matter insoluble in CS ₂ , percent	0.09	0.09	0.13	0.19	0.45	0.10	1.0-
Organic matter insoluble in CCl ₄ , do.	0.09	0.09	0.13	0.46	1.61	0.07	
Organic matter insoluble in 86° B. naphtha, do.	25.1	3.3	6.1	12.1	22.0	7.3	

¹ Failed to meet specification.² Loss during the pouring and cooling of the residue.

which had percentages of distillate at 600° F. and 680° F. that were 0.5 percent higher than the specification limit, all of the materials met the SC-2 specification. The test data do indicate, however, that although these materials met the same specification their physical and chemical properties differed widely. These differences will be discussed briefly.

The three steam-reduced products, samples 1, 2, and 3, had lower specific gravities than did samples 4, 5, and 6 and both the original materials and their distillation residues were homogeneous in the Oliensis test. When viewed under the microscope at 200 magnifications, samples 1 and 3 had clear fields both when undiluted and when diluted with 6 parts of carbon tetrachloride. Sample 2 showed a few carbonaceous particles under both conditions. The two cracked products, samples 4 and 5, and the blend, sample 6, had the highest specific gravities, were heterogeneous in the Oliensis test, and all contained a number of carbonaceous flecks when viewed microscopically.

Photographs of the Oliensis stains are given in figure 1, and photomicrographs of samples 2, 4, 5, and 6 are shown in figure 2.

All of the products except sample 5 were almost completely soluble in carbon disulphide, and sample 5 had less than 0.5 percent of insoluble matter. However, when carbon tetrachloride was used as the solvent, the solubilities of samples 4 and 5 were considerably decreased, showing the presence of carbenes in these two cracked materials. The percentage of material insoluble in 86° B. naphtha ranged from a maximum of 18.3 for sample 1 (the Mexican base material), to a minimum of 3.0 for sample 2 (the midcontinent residual). The two cracking coil residuals both contained less material insoluble in naphtha than did the steam-reduced Mexican residual.

BLENDING MATERIAL SHOWN TO BE UNSATISFACTORY IN ASPHALTIC RESIDUE TEST

The distillation curves shown in figure 3 illustrate the wide range in volatile matter present in samples 1, 3, and 5. Since gas oil was used as the diluent to reduce the viscosity of the base materials of samples 1 and 5 to specification limits, the high distillation losses un-

doubtedly resulted from the use of this cutting medium by the producer. As indicated by the total loss by weight in the distillation test, which includes the loss on cooling and pouring, sample 1 had the greatest amount of volatile constituents. Although no distillate was actually recovered from samples 2, 4, and 6, the distillation loss or loss on pouring and cooling of the residue to room temperature served to classify sample 2 as the least volatile material.

When the consistency of the distillation residue is considered in connection with the amount of volatile matter, the great difference in the hardening properties of these products is evident. The low amounts of volatile matter contained in samples 2, 4, and 6 indicate that they would be extremely slow hardening. Sample 3, although having a relatively high distillation loss, developed a residue with the same float-test consistency as sample 2. Samples 1 and 5 both had high percentages of distillation loss and the high float-test values for their distillation residues indicated that they were the most rapid hardening of the six materials.

The results of the volatilization tests on 20- and 50-gram samples (table 2) show in the same manner that sample 1 had the most volatile matter and was the most rapid hardening. Samples 2, 4, and 6 had the least volatile matter and were indicated by the test results to be the slowest-hardening materials. Although in the distillation test sample 5 lost more than sample 3, in the volatilization test sample 3 lost more than sample 5. However, in both tests sample 5 produced a slightly more viscous residue as measured by the float test.

A comparison of the solubilities of the residues from the distillation and volatilization tests showed that, except for the solubility in 86° B. naphtha of sample 5, the residues from volatilization were less soluble in carbon disulphide, carbon tetrachloride, and naphtha than were the residues from distillation, although in every case the samples lost more in the distillation test. The results of the solubility tests indicate that the volatilization test caused greater inherent alterations than did the distillation test.

The results of the asphaltic residue test are given in table 3. One residue was obtained by evaporating the materials at a temperature of 480° to 500° F., the con-

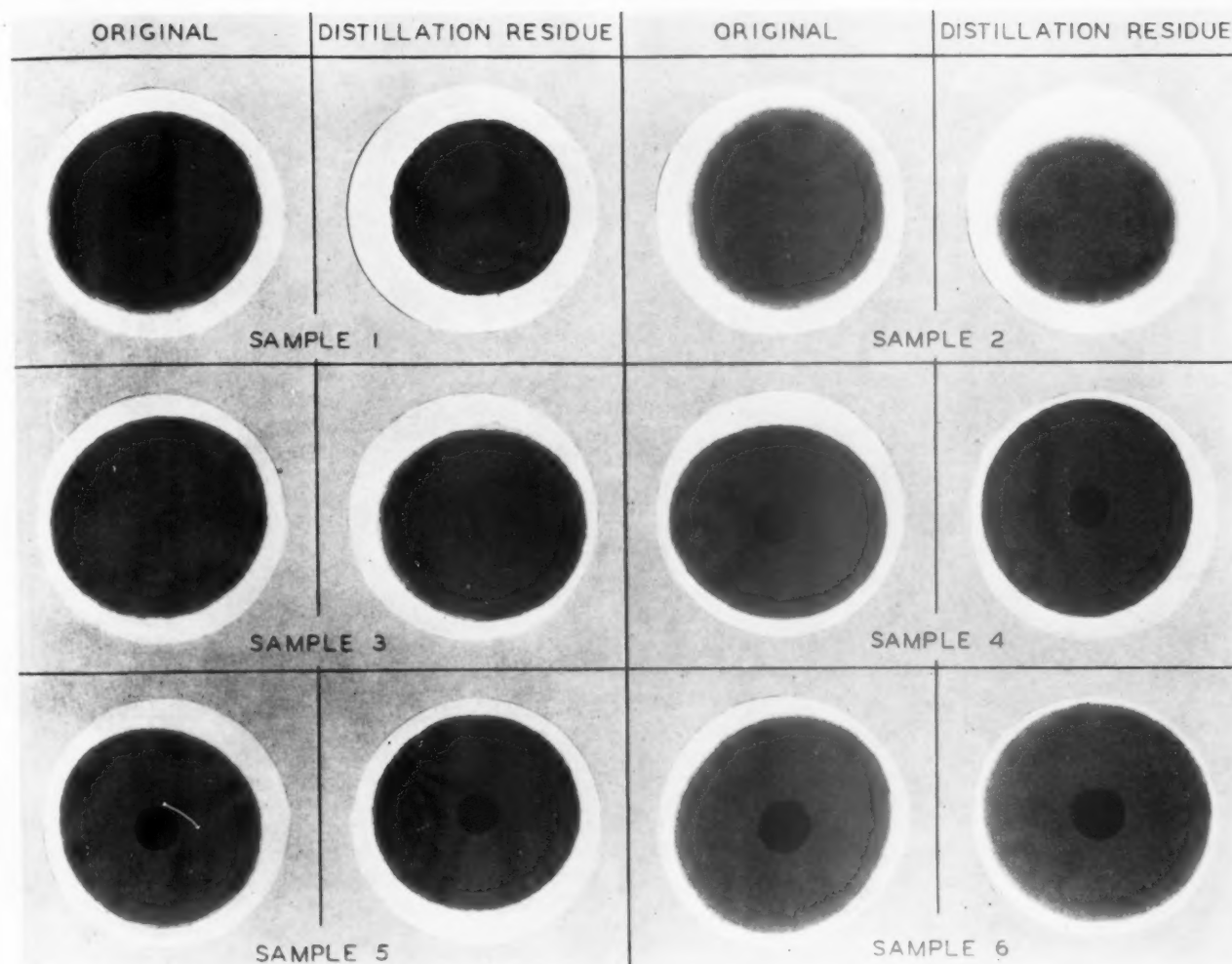


FIGURE 1.—APPEARANCES OF OLIENSIS SPOTS OF ORIGINAL MATERIALS AND THEIR DISTILLATION RESIDUES.

TABLE 2.—Results of volatilization tests

Sample	1	2	3	4	5	6
Loss at 325° F., 5 hr., 50 g. percent	12.3	0.2	5.7	1.1	5.4	0.7
Float of residue at 122° F. seconds	47	22	26	25	31	20
Loss at 325° F., 5 hr., 20 g. percent	19.4	0.2	10.7	1.8	9.2	1.1
Tests on residue of 20-gram sample:						
Float at 122° F. seconds	125	27	39	29	64	22
Organic matter insoluble in CS ₂ percent	0.10	0.10	0.23	0.21	0.94	0.23
Organic matter insoluble in CCl ₄ percent	0.10	0.10	0.23	0.76	2.59	0.41
Organic matter insoluble in 86° B. naphtha percent	33.7	3.9	8.4	16.1	21.6	9.0

trol temperature of the standard test method. The other residue was obtained by evaporating at a temperature of 400° to 420° F. Although sample 6 lost but little in the distillation and volatilization tests, the residues obtained were smooth and of even texture and there were no indications that the blend would become incompatible. However, when sample 6 was evaporated at a temperature of 480° to 500° F. to a penetration of 100, the residue became granular in texture and grayish black in color, and when tested had a high softening point and very little ductility.

It is of interest to note that sample 6, a combination of 50 percent of sample 2 which had an asphaltic residue of 72.1 percent and 50 percent of sample 4 which had an asphaltic residue of 64.5 percent, had only 54.6 percent of asphaltic residue of 100 penetration. When an

attempt was made to reduce the sample at the lower temperature (400°–420° F.) it separated into two parts, one soft and greasy, the other hard and granular. These could not be refluxed and reduction to a satisfactory residue was impossible.

TEST RESULTS SHOW NON-ASPHALTIC CHARACTER OF SAMPLE 2

Of the other materials, sample 5 was most rapidly reduced to the desired penetration, followed closely by sample 1; samples 4 and 3 were next; and sample 2 took an exceedingly long time to be reduced. At the lower temperature the time of reduction for all samples was appreciably increased, and the percentage of residue obtained was in every case greater than that obtained under the standard test. The increase in percentage of residue ranged from 2.3 percent for sample 1 to 11.5 percent for sample 2 with an average increase for the five samples of 5.2 percent.

Under both temperatures of reduction samples 1, 3, 4, and 5 produced residues having high ductility at 77° F., and both residues of sample 1 had good ductility at 34°–35° F. The residues of samples 3 and 5 obtained at the higher test temperature had no ductility at 34°–35° F. The residue of sample 3 obtained at the lower temperature had a ductility of 5.5 centimeters at 34°–35° F. and the residue of sample 5, although it

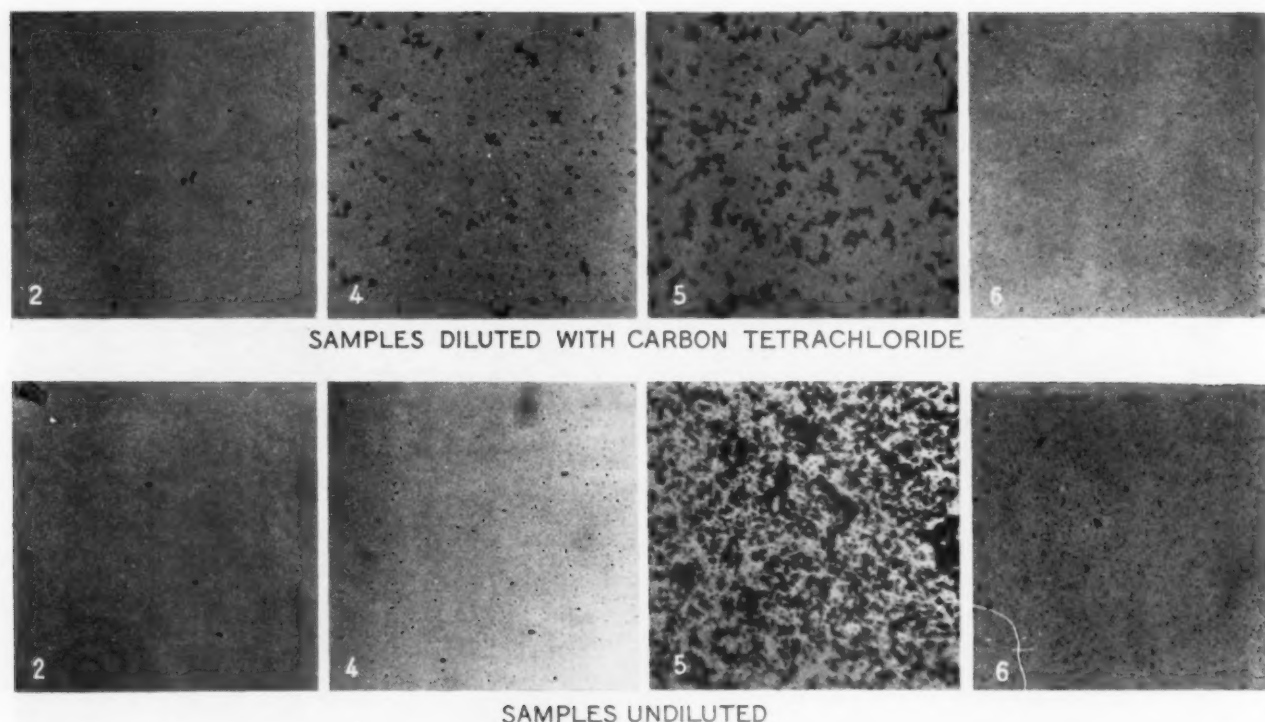


FIGURE 2.—PHOTOMICROGRAPHS OF DILUTED AND UNDILUTED ASPHALTIC MATERIALS. MAGNIFIED 115 DIAMETERS.

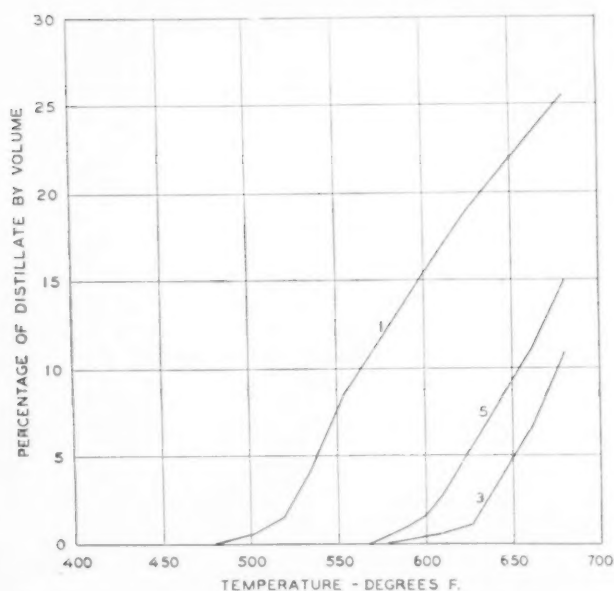


FIGURE 3.—DISTILLATION CURVES OF SAMPLES 1, 3, AND 5.

did not pull to a thread, had a ductility of 3.0 centimeters. Both residues of sample 4 had no ductility at 34°-35° F.

Both of the asphaltic residues of samples 2 had low ductility at 77° F. but retained a high percentage of their original ductility when tested at 34°-35° F. The high penetrations obtained on the residues of this sample at 32° F., together with their high softening points, indicate that these residues were the least susceptible to temperature change. The residues were greasy, however, and appeared much harder than the penetration test indicated. The character of the asphaltic

residues, the long time of reduction to the desired penetration, together with the low amount of material insoluble in naphtha in the original material, show that the base petroleum was essentially a paraffin-base oil.

Although viscosity limits in specifications for liquid bituminous materials only insure the use of products of comparable workability and initial consistency, viscosity tests made at various temperatures are of value in classifying various types of material meeting the same specification. Viscosity tests made at various temperatures also can be used to distinguish different types of material according to their susceptibility to temperature change. Accordingly, the Furol viscosities of the six samples under investigation were determined at 104°, 122°, 140°, 158°, and 180° F.

When the resulting viscosities are plotted against the temperature on logarithmic scales (fig. 4) the points for each sample fall generally along a straight line. The equation of this line is $\log V = -a \log t + K$, where V is the Furol viscosity in seconds, t is the temperature in degrees Fahrenheit, $-a$ is the slope of the curve, and K is the Y intercept. According to this equation K is also the logarithm of the viscosity at 1° F. The coefficient $-a$ may be used as a susceptibility factor, the greater the numerical value of $-a$ the greater is the susceptibility of the material. Applying this factor, it is seen that sample 4 was the most susceptible to changes in temperature, followed in order by samples 6, 3, 5, 2, and 1.

The float-test consistency of these materials as determined at 77° F. is of interest in demonstrating the unusual character of sample 2. A study of a large number of asphaltic, semiasphaltic, and cracking-coil residuals of the same consistency as the six materials used in this study showed that for materials of the same viscosity at 122° F. cracking-coil products, because of their greater susceptibility to temperature change, had the

TABLE 3.—Results of asphaltic residue tests

	Samples reduced at 480°-500° F.						Samples reduced at 400°-420° F. ¹				
	1	2	3	4	5	6	1	2	3	4	5
Time of reduction.....minutes..	39	600	83	81	35	300	275	1,600	400	400	200
Residue.....percent..	67.1	72.1	62.6	64.5	74.4	54.6	69.4	83.6	66.7	69.3	78.0
Tests on residue:											
Penetration at 77° F., 100 grams, 5 seconds.....	86	99	110	109	95	103	104	100	104	83	106
Penetration at 32° F., 200 grams, 60 seconds.....	32	59	18	21	22	27	39	55	23	19	23
Softening point.....°F..	122	126	109	106	111	139	121	139	111	111	111
Ductility at 77° F.....centimeters..	90	11	110+	110+	110+	4.5	110+	4.5	110+	110+	110+
Ductility at 34-35° F.....centimeters..	5.5	3.3	0	0	0	0	6.5	2.5	5.5	0	13.0
Organic matter insoluble in CS ₂percent..	0.10	0.14	0.04	1.33	2.60	9.33	0.09	0.11	0.09	1.94	2.56
Organic matter insoluble in CCl ₄percent..	28.4	22.5	15.3	31.1	25.8	32.4	28.7	25.0	18.3	27.3	25.6

¹ Sample 6 separated into 2 parts which could not be refluxed.² Sample broke, not a normal test.

higher float values when tested at 77° F. The high float of sample 2 when tested at 77° F. is, however, typical of results on nonasphaltic residuals of comparable viscosity.

MATERIALS EXPOSED IN VARIOUS FILM THICKNESSES FOR VARIOUS PERIODS

In exposing the materials to the action of sunlight, heat, and air, the test procedure followed that used in previous investigations by the Bureau. In this study, however, the materials were exposed not only in layers $\frac{1}{8}$ -inch thick but also in $\frac{1}{16}$ - and $\frac{1}{32}$ -inch layers. Three samples of each thickness were prepared of each material. Each sample, containing 50 cubic centimeters of material, was placed in a seamless, flat-bottom aluminum pan $\frac{3}{8}$ inch deep and of sufficient diameter to give the desired film thickness. The samples were placed in the exposure boxes on June 6, 1934. One set was removed and tested at the end of 5 weeks, another at 10 weeks, and the third at 15 weeks. The losses of volatile matter were determined by weighing the samples at the end of 2, 12, 35, 70, and 105 days.

During the exposure period hourly temperature readings were made daily from 9 a. m. to 4 p. m. The maximum daily temperature within the boxes varied from 85° to 185° F. with an average daily maximum of 145° F. The maximum temperatures occurred on days with the maximum possible sunshine. On cloudy days there was little difference between the temperature inside and outside the boxes. United States Weather Bureau reports showed that the samples exposed for 5, 10, and 15 weeks were subjected to 368, 663, and 904 hours of sunlight, respectively. The appearances of the samples exposed in $\frac{1}{8}$ -inch films, after 15 weeks of exposure, are shown in figure 5. The results of tests on the residues are given in table 4.

The residues shown in figure 5 are briefly described as follows:

- Sample 1: Rough, dull center, brown streak when scratched, some glossy material around edges in cracks.
- Sample 2: Smooth, glossy, greasy, slightly mottled.
- Sample 3: Smooth, glossy, sticky.
- Sample 4: Smooth, glossy, slightly sticky.
- Sample 5: Rough surface, raised portions dull, depressions slightly glossy.
- Sample 6: Generally glossy, rough; cracks filled with soft material which was fluid and greasy.

Although not indicated in the table because of variations in the losses by individual specimens of the same sample, each individual specimen, with the exception of those of sample 2 which gained weight throughout the test, lost weight progressively as the time of exposure increased. The table shows that the greatest losses

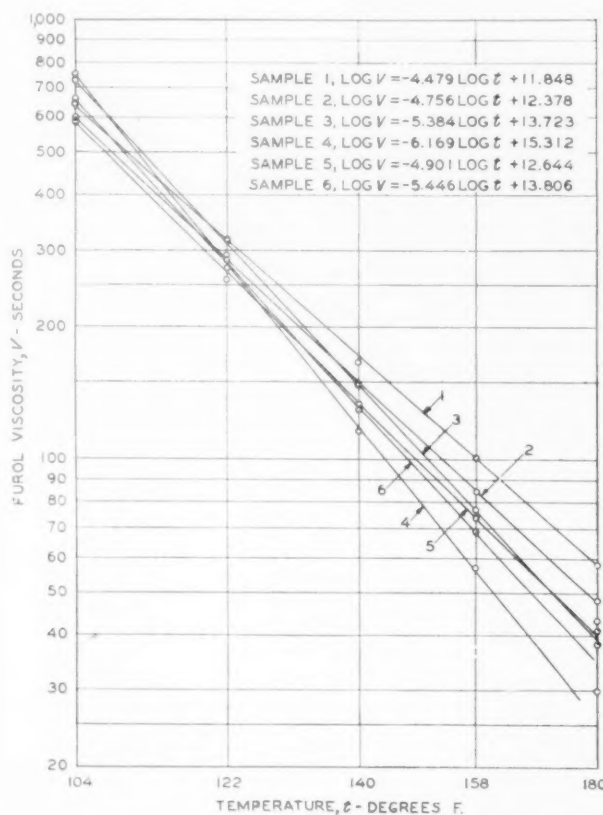


FIGURE 4.—RELATIONS BETWEEN FUIROL VISCOSITY AND TEMPERATURE FOR THE VARIOUS SAMPLES.

occurred in the thinnest films. The order of the losses at the end of 15 weeks is in substantial agreement with the order of the losses in the distillation and volatilization tests.

In figure 6 the losses at various periods of exposure are plotted for samples 1, 3, 4, and 5. The losses at 2, 12, and 35 days are the averages for the three specimens of each sample originally exposed. The losses at 70 days are the averages for the materials tested at the end of 10 and 15 weeks, while the losses at 105 days are the losses for the specimens of each sample tested at the end of 15 weeks. This accounts for the fact that the $\frac{1}{8}$ -inch film of sample 3 appeared to have lost more in 10 weeks than in 15 weeks.

Sample 1 not only lost more than the other samples but lost at a faster rate. In 12 days sample 1 had lost, depending upon the film thickness, from 75 to 79 percent of its total loss in 15 weeks. In the same time

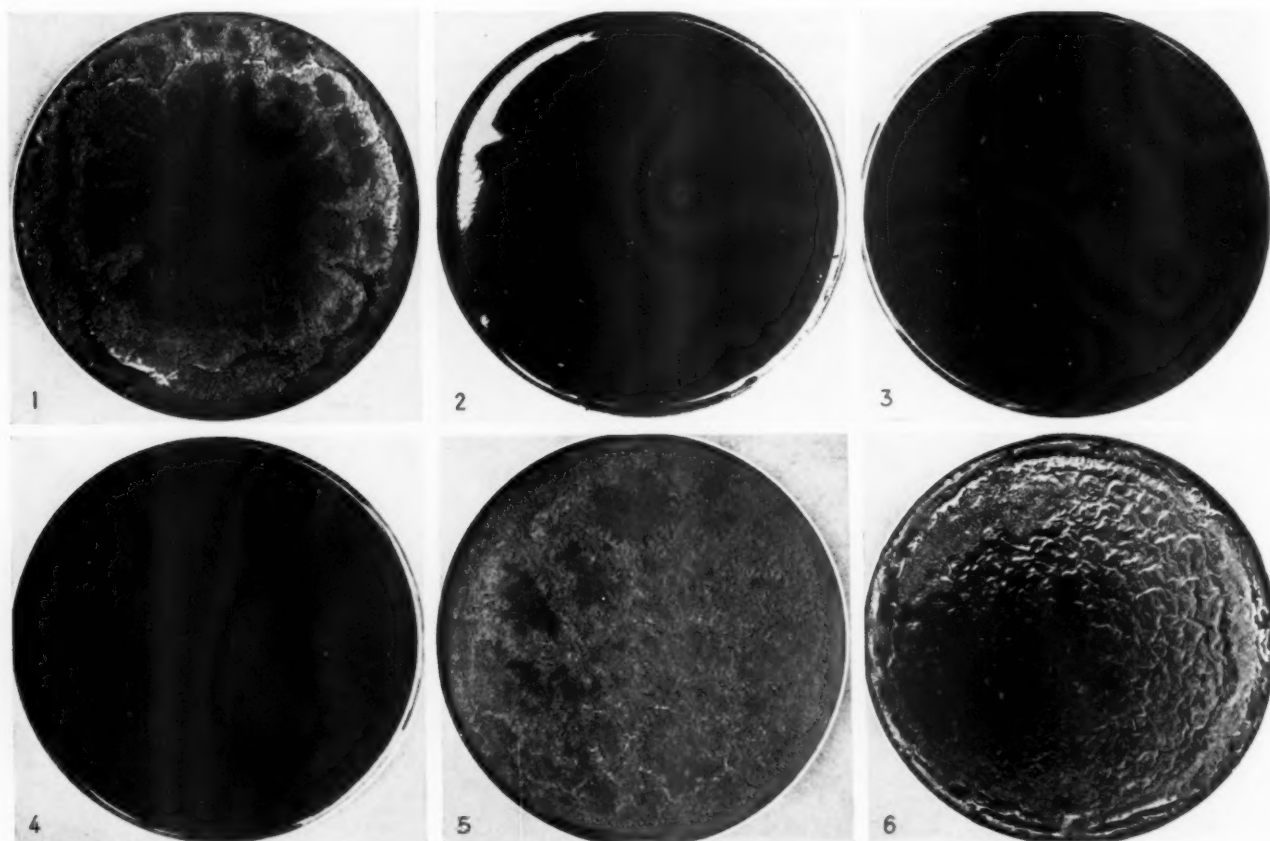


FIGURE 5.—APPEARANCES OF SURFACES OF THE $\frac{1}{8}$ -INCH FILMS OF LIQUID ASPHALT AFTER 15 WEEKS OF EXPOSURE.

sample 5 had lost from 45 to 72 percent of its total loss; sample 3 lost from 43 to 56 percent; and sample 4 lost from 14 to 30 percent. In 35 days sample 1 had lost from 90 to 97 percent of its total loss; sample 5 lost from 89 to 91 percent; sample 3 lost from 80 to 86 percent; and sample 4 lost from 49 to 61 percent.

These comparisons show that, although the volatilization test gave an indication of the comparative volatility upon exposure, the distillation test gave a better idea of the probable rate of volatility. The effect of the gas oil used by the producer for reducing the base materials of samples 1 and 5 to the desired consistency was shown by the greater rate of volatility of these two materials under both laboratory and exposure conditions.

MATERIALS EXPOSED IN THINNEST FILMS MOST HIGHLY ALTERED

Within a week after the start of exposure, sample 6, separated into two parts, one soft and greasy, the other hard and granular. These two components could not be fluxed together and the tests on the residues were made after the samples had been mixed to as uniform a condition as possible. It will be noted that neither the distillation nor the volatilization tests gave any indication that this blend might prove to be an incompatible mixture. The granular residue obtained from the asphaltic residue test made at the standard temperature was indicative of some instability, and the behavior of the material in the asphaltic residue test, run at a temperature of 400°–420° F., was further evidence that this material might prove to be a non-cohesive and unsatisfactory product.

Table 4 shows that the thinner films at any exposure period had the harder residues. Excluding sample 6,

sample 2 was the slowest-hardening material. After 15 weeks the specimen of sample 2 exposed in a film one thirty-second inch thick had hardened to a residue having a penetration of 211. This residue was very greasy and unlike a normal asphaltic material of similar consistency. It had a float value greater than 1,200 seconds at 122° F., a high softening point for material of this penetration, and very little ductility at 77° F. All other exposure residues of sample 2 had penetrations over 300 and were also greasy.

The remaining 4 materials (samples 1, 3, 4, and 5) had hardened to a much greater extent. When exposed in $\frac{1}{8}$ -inch films, sample 1 was the hardest after each of the three test periods, followed by samples 5, 3, and 4. When exposed in $\frac{1}{16}$ -inch films, sample 1 was the hardest after each of the test periods, and at the end of 5 and 10 weeks samples 5, 3, and 4 followed in that order. However, after the last 5-week period sample 4 had increased in hardness until it was second to sample 1, followed by samples 5 and 3. When exposed in a $\frac{1}{32}$ -inch film sample 5 was the hardest at the end of 5 weeks, followed in order by samples 1, 4, and 3. At the end of 10 weeks sample 1 was the hardest, followed by samples 4, 5, and 3, and at the end of 15 weeks sample 4 was the hardest, followed by samples 1 and 5 with the same penetration, and sample 3 was the softest, excluding samples 2 and 6.

For the thicker films and short periods of exposure the hardness of the residues was roughly proportional to the loss in weight. In the thinner films and for longer periods of exposure, the character of the material apparently influenced the hardening of the exposed residues and the cracked materials, samples 4 and 5, ultimately became the hardest.

TABLE 4.—Results of tests on thin films of liquid asphalt exposed under glass

Time of exposure	5 weeks (368 hours of sunlight)						10 weeks (663 hours of sunlight)						15 weeks (904 hours of sunlight)					
Sample no.	1	2	3	4	5	6 ¹	1	2	3	4	5	6 ¹	1	2	3	4	5	6 ¹
Sample exposed in 1/8-inch film:																		
Loss.....percent.	22.4	-1.0	11.3	1.6	13.1	0.1	23.9	-1.1	15.1	2.8	15.1	0.1	23.2	-0.9	13.8	4.1	15.0	0.6
Float at 122° F.....seconds	59	50	95	58	140	49	38	73	252	100	60	51	82	206	147	55	71	71
Penetration at 77° F., 100 grams, 5 seconds.....° F.	144	91	77	67	131	167	167	91	102	85	162	41	163	99	104	165	5.5	1.48
Softening point.....centimeters	8.5	91	77	67	8.8	4.7	110+	91	110+	85	2.8	5.5	110+	99	104	165	5.5	1.48
Ductility at 77° F.....centimeters	0.21	0.21	0.21	0.83	0.92	0.35	0.46	0.21	0.21	0.21	0.58	0.66	0.14	0.11	0.11	2.87	1.89	1.48
Organic matter insoluble in CCl ₄percent	0.14	0.14	0.14	2.64	4.49	1.70	0.53	0.10	0.09	4.76	5.63	2.29	0.75	0.07	0.13	6.21	6.45	5.09
Organic matter insoluble in 86° B. naphtha.....percent	35.0	8.8	17.8	21.0	28.4	16.1	37.0	11.0	24.1	24.4	32.3	21.0	39.0	12.8	23.5	27.8	33.0	25.2
Sample exposed in 1/16-inch film:																		
Loss.....do.	23.1	-1.1	14.9	2.4	15.6	0.6	24.3	-1.3	17.8	4.3	16.8	0.7	25.5	-1.3	17.7	5.7	16.8	1.1
Float at 122° F.....seconds	74	74	230	115	29	67	112	112	127	122	215	93	214	132	149	215	136	136
Penetration at 77° F., 100 grams, 5 seconds.....° F.	40	161	90	100	87	175	25	96	127	122	215	18	226	114	132	149	215	215
Softening point.....centimeters	5.0	110+	110+	110+	1.7	2.6	26.5	26.5	6.0	0.5	2.31	1.42	0.32	0.22	0.32	6.51	5.31	5.13
Ductility at 77° F.....centimeters	0.40	0.45	0.45	0.45	1.03	0.87	0.89	0.13	0.14	0.08	9.40	5.45	1.67	0.39	0.26	12.62	11.43	8.84
Organic matter insoluble in CCl ₄do.	0.45	0.45	0.45	0.45	7.19	2.87	0.89	0.13	0.14	0.08	9.40	5.45	1.67	0.39	0.26	12.62	11.43	8.84
Organic matter insoluble in 86° B. naphtha.....percent	37.8	11.8	23.1	25.3	34.0	22.9	38.7	16.0	31.4	30.6	38.5	34.5	45.1	19.3	32.2	34.7	41.0	35.5
Sample exposed in 1/32-inch film:																		
Loss.....do.	23.6	-1.4	16.5	4.6	16.8	1.3	25.5	-1.3	18.6	7.1	17.8	0.9	26.1	-1.4	20.1	7.9	18.4	1.5
Float at 122° F.....seconds	134	134	134	134	129	129	1,200+	1,200+	26	18	156	9	1,200+	1,200+	15	5	9	1,200+
Penetration at 77° F., 100 grams, 5 seconds.....° F.	35	188	102	120	124	205	219	126	145	173	226	247	211	131	175	202	256	300+
Softening point.....centimeters	3.5	11	55	11	0.3	1.0	1.0	4.5	0	0	0	0	3.0	3.0	1.0	0	0	0
Ductility at 77° F.....centimeters	0.52	0.17	0.12	4.67	4.51	2.98	1.88	0.73	0.50	8.13	10.03	9.20	2.88	1.65	1.21	12.77	11.44	12.52
Organic matter insoluble in CCl ₄do.	0.62	0.18	0.20	9.64	10.84	7.90	1.98	0.74	0.45	15.66	17.14	14.65	3.22	2.06	1.40	20.12	18.90	16.42
Organic matter insoluble in 86° B. naphtha.....percent	41.3	15.8	27.9	30.4	40.3	32.5	44.7	22.7	34.6	37.7	46.2	43.1	49.7	27.3	39.4	43.6	50.0	44.9

¹ Sample separated into 2 parts which could not be refluxed.² Sample broke, not a normal test.

All of these extremely hard residues had little if any ductility. All of the final residues had high percentages of material insoluble in 86° B. naphtha and had, especially in the case of the cracked products, including sample 6, large amounts of material insoluble in carbon disulphide and carbon tetrachloride. The percentage of insoluble material was greatest in the residues of the thinnest films, indicating that greater internal alterations had taken place in these samples.

The percentages of material insoluble in 86° B. naphtha in the residues after exposure are plotted in figure 7. As the volatile constituents of the liquid asphalts evaporated, the material insoluble in naphtha was concentrated in the residues. Assuming no change except that resulting from loss of volatile matter, the theoretical percentages of material insoluble in naphtha that should be present in the different residues are shown in figure 7. Only in the case of samples 1 and 5 was there an appreciable theoretical increase in insoluble material caused solely by loss of volatile matter and the resulting concentration.

The curves show that all of the residues from exposure contained considerably more than the calculated amount of material insoluble in 86° B. naphtha. The percentage of material insoluble in naphtha actually present in the residues of the 1/32-inch films after 15 weeks was twice the calculated percentage for sample 1 and 8.7 times the calculated percentage for sample 6.

MODIFIED OLIENSIS SPOT TEST USED IN STUDYING EXPOSURE RESIDUES

One sample of each material was also exposed in a 1/8-inch film in the open air adjacent to the circular track. These samples were tested at the end of 15 weeks and the results are given in table 5. Sample 6 became quite granular in texture and greasy in appearance, but the incompatibility of the blend was not as pronounced as in the exposure-box tests. All of the materials had considerably less loss in weight than occurred in the distillation test and developed residues much harder

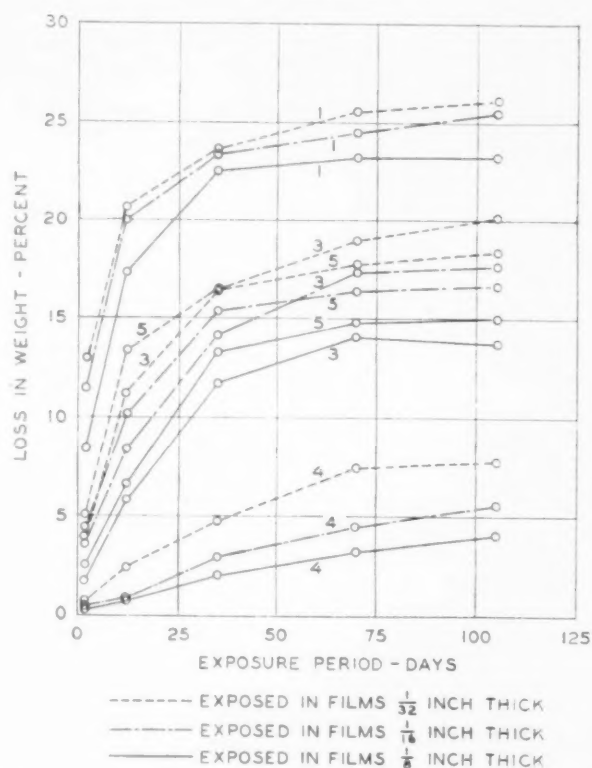


FIGURE 6.—RATE OF LOSS BY ASPHALTIC MATERIALS EXPOSED IN THIN FILMS.

than those from distillation. Sample 1 lost the most and became the hardest. While samples 3 and 5 lost about equal amounts, sample 5 evidenced the greater hardening properties.

That the asphaltic residue test cannot be used to estimate the amount of 100 penetration asphalt a liquid asphalt will ultimately develop under certain conditions is illustrated by the behavior of sample 1. In the

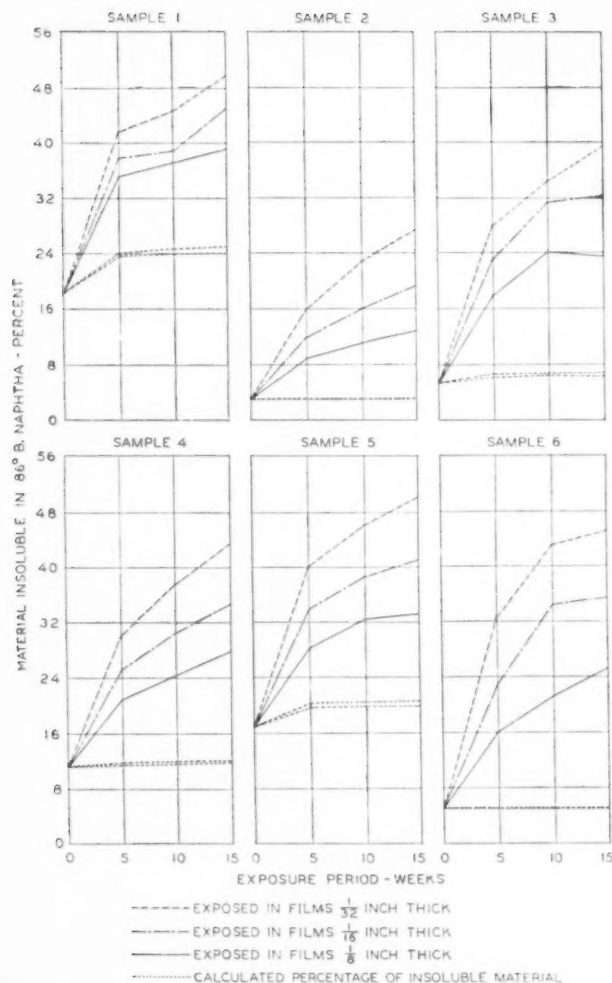


FIGURE 7.—PERCENTAGES OF MATERIAL INSOLUBLE IN 86° B. NAPHTHA IN THE RESIDUES AFTER VARIOUS PERIODS OF EXPOSURE.

asphaltic residue test this sample lost 32.9 percent and in the open-air exposure the loss was only 19.7 percent, yet the two residues had comparable consistencies as measured by the penetration test. The results indicate that 15 weeks of exposure in the open air was slightly less severe than 5 weeks of exposure in the glass-covered boxes.

In a previous study of liquid asphalts, it was found that all of the materials that were originally homogeneous became heterogeneous after 5 weeks of exposure under conditions similar to those existing in the exposure tests in glass-covered boxes described in this report. The heterogeneity apparently increased, but the spot test made in accordance with the original description of the Oliensis method⁴ permitted only a rough approximation to be made of the degree of heterogeneity and rate of increase in the residues exposed.

At the 1936 meeting of the American Society for Testing Materials, Oliensis⁵ described a modification of his method that permits the degree of heterogeneity to be determined quantitatively. When an asphaltic ma-

⁴ A Qualitative Test for Determining the Degree of Heterogeneity of Asphalts, by G. L. Oliensis. Proceedings of the American Society for Testing Materials, 1933.

⁵ A Further Study of the Heterogeneity of Asphalts—A Quantitative Method. Proceedings of the American Society for Testing Materials, 1936. Also see The Oliensis Spot Test Improved, by R. H. Lewis and J. Y. Welborn. PUBLIC ROADS, vol. 18, no. 3, May 1937.

TABLE 5.—Results of tests on $\frac{1}{16}$ -inch films of liquid asphalt exposed in open for 15 weeks

Sample no.	1	2	3	4	5	6
Loss in 15 weeks.....percent	19.7	-2.5	9.1	0.1	10.6	1.0
Float at 122° F.....seconds	1,312	50	75	50	343	54
Penetration at 77° F., 100 grams, 5 seconds..... $\frac{1}{16}$ inch	108	108	108	108	108	108
Softening point.....° F	123	123	123	123	123	123
Ductility at 77° F.....centimeters	25	25	25	25	25	25
Organic matter insoluble in CS_2percent	0.48	0.21	0.17	0.77	0.89	0.88
Organic matter insoluble in CCl_4percent	0.47	0.17	0.14	2.23	3.92	1.75
Organic matter insoluble in 86° B. naphtha.....percent	33.0	8.1	16.1	19.8	27.4	16.2

¹ Material granular and nonuniform in texture.

terial gives a positive stain after dispersion in the standard 50° B. naphtha, the material may be considered as heterogeneous. If xylene is added to the naphtha in increasing amounts and the asphaltic material is dispersed in the same volume of the blended solvent as of the naphtha, a concentration may be reached that will produce a negative stain. The degree of heterogeneity may then be expressed by the percentage of xylene that must be added to the standard naphtha in order to produce a negative stain. This percentage is called the xylene equivalent.

In practice the laborious task of determining the exact percentage of xylene at which the change from positive to negative occurs is not justified, and, therefore, the xylene equivalent is generally expressed by limiting percentages. Thus, a xylene equivalent of 50-55 means that with 50 percent xylene the material gave a positive stain, and with 55 percent xylene a negative stain was obtained. If a positive spot is obtained with xylene alone, the degree of heterogeneity is not determinable with this solvent.

XYLENE EQUIVALENT INCREASED AS EXPOSURE TIME INCREASED AND AS FILM THICKNESS DECREASED

As previously stated, samples 1, 2, and 3 originally and after distillation gave negative stains when dispersed in 50° B. naphtha. Samples 4, 5, and 6 gave positive stains not only with the standard solvent but also with 100 percent xylene. These three materials were, therefore, outside the scope of the quantitative test for heterogeneity.

Samples 1, 2, and 3, when exposed under glass for 5, 10, and 15 weeks and in the open air for 15 weeks, produced residues which gave positive stains with the standard naphtha. The xylene equivalents of the residues from the exposures under glass are given in table 6.

It is seen that the xylene equivalent at the end of each test period increased as the film thickness decreased. For each film thickness, except the $\frac{1}{16}$ - and $\frac{1}{32}$ -inch films of sample 1, the xylene equivalent increased as the time of exposure increased. The reason for the slightly lower xylene equivalents obtained on the 10-week residues of the $\frac{1}{16}$ - and $\frac{1}{32}$ -inch films of sample 1, as compared to those obtained on the 5-week residues of the same film thickness, cannot be explained.

If the solubilities of the residues that produced xylene-insoluble spots are compared with the solubilities of the $\frac{1}{16}$ -inch film of sample 2 after 15 weeks of exposure (table 4), it is seen that this residue of sample 2 had a larger percentage of material insoluble in carbon disulphide than two of the residues reacting positive in 100 percent xylene and more material insoluble in carbon tetrachloride than three of the residues whose heterogeneity was not determinable by this method.

TABLE 6.—Xylene equivalents of residues of homogeneous materials exposed under glass

Sample no.	Film thickness	Xylene equivalents after exposure for—		
		5 weeks	10 weeks	15 weeks
	Inch			
1	1/8	4-8	0-2	8-16
	1/16	8-12	4-8	(1)
	1/32	12-16	(1)	(1)
2	1/8	0-2	16-20	36-40
	1/16	28-32	36-40	56-60
	1/32	48-52	60-64	68-72
3	1/8	24-28	32-36	36-40
	1/16	36-40	44-48	48-52
	1/32	48-52	64-68	(1)

(1) Xylene insoluble.

The residue of sample 2, however, had a xylene equivalent of 68-72. Evidently there are essential differences in the character of the carbonenes and free carbon in these residues that have a direct bearing on their ready dispersion in either 100 percent xylene or the naphtha-xylene blend.

The SC-2 type of liquid asphaltic material, when used in the construction of oil-processed roads, is generally mixed with aggregate graded in size from 1 inch maximum to dust. Fine aggregate mixtures, however, were used in this investigation because greater uniformity in the composition of the mixed surfaces could be obtained in the relatively small test sections, and the fine-graded aggregate is more suitable for the preparation of both Hubbard-Field stability and toughness specimens.

Preliminary tests were made on an indoor circular track with mixtures containing various proportions of Potomac River sand, limestone dust, and the California residual, sample 3. A mixture containing 85 percent of sand and 15 percent of dust, by weight, was used. This aggregate, when separated on standard sieves, had the following grading:

	Percent
Passing no. 10, retained on no. 20	10.2
Passing no. 20, retained on no. 30	14.1
Passing no. 30, retained on no. 40	20.9
Passing no. 40, retained on no. 50	20.4
Passing no. 50, retained on no. 80	15.0
Passing no. 80, retained on no. 100	1.8
Passing no. 100, retained on no. 200	2.6
Passing no. 200	15.0

This aggregate, when combined with 7.5 percent of oil, produced a mixture having sufficient stability to withstand considerable traffic without undue displacement. This percentage by weight of asphaltic material was equal to 18.3 percent by volume and this percentage by volume was used in all mixtures. Because of the differences in the specific gravities of the bituminous materials, the percentage of oil by weight of the mixture varied from 7.3 for sample 2 to 8.1 for sample 5. In this way the void-filling capacity and film thickness of the asphaltic materials were held constant for all of the mixtures.

Sufficient amounts of each mixture were made to construct the track sections and provide excess material for Hubbard-Field stability and toughness cylinders. Additional cylinders 2½ inches high and 2 inches in diameter were also prepared and stored in forms, their upper surfaces being exposed in the immediate vicinity of the track to the same climatic conditions as the track sections. These cylinders were used to replace cores taken from the track surfaces during the course of the experiment.

TABLE 7.—Results of tests on Hubbard-Field cylinders

Age when tested (weeks)	Loss of bitumen by sample no.—						Stability at 77° F. of sample no.—					
	1	2	3	4	5	6	1	2	3	4	5	6
Immediately	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
	375	375	325	400	425	350						

AGED IN OVEN AT 140° F.

1	12	3	7	3	7	3	1,050	425	525	525	775	425
2	14	3	7	2	9	3	1,425	350	550	500	900	500
3	16	3	8	3	10	3	1,850	525	750	625	1,025	525
4	17	3	9	4	11	4	1,825	475	775	625	1,150	525
5	18	3	10	4	12	4	2,200	525	875	750	1,250	550

AGED IN GLASS-COVERED EXPOSURE BOXES

1	8	1	3	1	4	1	825	425	500	450	850	475
3	15	1	8	2	9	2	1,900	500	900	750	1,525	700
5	18	0	9	2	10	1	2,700	575	1,200	875	1,850	725
10	20	1	11	3	12	3	3,500	625	1,600	1,200	2,150	1,050
15	22	1	13	4	13	3	4,100	800	2,200	1,725	2,650	1,325
20	21	0	12	4	13	2	4,175	750	2,000	1,600	2,600	1,100

AGED IN CANVAS-COVERED EXPOSURE BOXES

1	3	0	1	0	0	0	500	475	350	450	650	425
3	6	0	2	1	3	0	725	600	450	450	775	450
5	7	0	1	0	3	0	800	475	425	425	775	450
10	11	0	2	0	5	1	1,200	575	500	425	900	500
15	13	0	4	0	6	1	1,550	600	675	500	1,100	575
20	12	0	3	0	5	0	1,525	450	600	525	1,100	575

AGED IN OPEN AIR ADJACENT TO TRACK

1	4	0	1	0	2	0	525	450	400	475	650	400
3	8	1	3	1	4	1	850	625	575	425	850	475
5	10	1	4	0	5	0	1,250	550	600	550	1,000	475
10	14	1	4	1	7	1	1,550	650	800	875	1,225	500
15	16	1	7	1	8	1	2,050	750	1,100	725	1,550	675
20	15	0	6	1	7	1	1,900	650	1,000	675	1,425	675

AGED IN OPEN AIR, ALTERNATELY WET AND DRY

20							1,925	550	600	700	1,300	750
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CYLINDERS AGED IN GLASS-COVERED EXPOSURE BOXES HAD HIGHEST STABILITIES

The stability cylinders were made in sets of three. Each cylinder, containing about 100 grams of aggregate, was compacted at 77° F. under a load of 3,000 pounds per square inch. One set of cylinders of each sample was immediately tested for stability at 77° F. Five sets were aged in an oven at 140° F., and one set of each was tested for stability at 77° F. at the end of 1, 2, 3, 4, and 5 weeks. Six sets of cylinders of each mixture were aged in glass-covered exposure boxes, six sets in canvas-covered exposure boxes, and six sets in the open air adjacent to the track. One set from each condition of exposure was tested at the end of 1, 3, 5, 10, 15, and 20 weeks.

All samples were weighed before and after aging and the loss in weight was expressed as the percentage of bitumen lost. One set of cylinders for each mixture was also aged out of doors near the track for 20 weeks in a large shallow pan. The cylinders were covered with water every night and exposed uncovered during the day after the removal of the water each morning. At the end of the test period the condition of the specimens was noted and each was tested for stability.

The results of the Hubbard-Field stability test given in table 7 indicate that, although the cylinders of all the samples had about the same initial stability, the final

TABLE 8.—Results of tests on bitumen recovered from Hubbard-Field cylinders after aging

Sample no.	1	2	3	4	5	6
Original asphaltic material dissolved in benzol and recovered:						
Float at 77° F.....seconds..	29	187	35	55	48	63
Organic matter insoluble in CCl ₄ ..percent..	0.06	0.04	0.05	0.20	2.06	0.16
Organic matter insol. in 86° B. naphtha..percent..	19.1	3.7	5.4	12.0	18.1	7.4
Bitumen recovered from cylinders aged for 20 weeks in glass-covered boxes:						
Float at 122° F.....seconds..	1,084	45	100	63	1,200	203
Penetration at 77° F., 100 grams, 5 seconds..	122				245	
Organic matter insoluble in CCl ₄ ..percent..	0.24	0.41	0.14	1.82	0.46	0.85
Organic matter insoluble in 86° B. naphtha..percent..	30.5	7.6	18.6	22.4	25.8	14.9
Bitumen recovered from cylinders aged for 20 weeks alternately wet and dry:						
Float at 77° F.....seconds..	683	692	75	114	395	2,400+
Float at 122° F.....seconds..	100	35	30	31	56	57
Organic matter insoluble in CCl ₄ ..percent..	0.20	0.07	0.14	0.40	0.22	0.93
Organic matter insoluble in 86° B. naphtha..percent..	24.1	5.0	9.8	16.8	21.8	13.1

stabilities under any method of aging varied greatly. Cylinders of sample 1 had the highest ultimate stability and percentage of loss of bitumen, and those of sample 5 had the next highest stability and percentage of loss. Cylinders of sample 3, although losing almost as much as the cylinders of sample 5, had only slightly higher stability than the cylinders of sample 4, which had a small loss of volatile matter under all methods of aging. Cylinders of samples 2 and 6 lost little and developed comparatively little stability. Cylinders of sample 6 had slightly greater stabilities than those of sample 2.

The final stabilities under each method of aging, plotted in figure 8, show that aging in the glass-covered exposure boxes gave the highest stability, and aging in the canvas-covered boxes generally gave the lowest stability. The stabilities obtained by aging in the oven at 140° F. for 5 weeks, by aging in the open air for 20 weeks, and by aging under alternately wet and dry conditions for 20 weeks, were all about the same except in the case of sample 3. The stabilities of the specimens of sample 3, exposed alternately wet and dry, were as low as those of the specimens exposed under canvas covers.

The specimens exposed under alternately wet and dry conditions varied somewhat in behavior. The cylinders of sample 1 had some slight cracks and had swelled so that it was difficult to place them in the stability testing mold. Those of sample 2 had also swelled and half of the specimens had split in two horizontally. The cylinders of samples 3 and 4 had small blisters on top while those of samples 5 and 6 remained in good condition. Although the outer surfaces of the specimens of the other five samples were dry and dull colored, those of sample 6 were always glossy-black and greasy, probably because of the tendency of this blend to separate into two parts and the subsequent movement of the oily fraction to the surface. This same behavior was also noted in the stability specimens exposed adjacent to the track.

The behavior of the cylinders under these various conditions indicated that the hardening properties of sample 1, and to a lesser extent samples 3, 4, and 5, might vary considerably under various temperature and climatic conditions. Samples 2 and 6, because of their low volatility in the laboratory heat tests, would not be expected to show a great difference in behavior under such conditions as might normally occur in actual use.

After the specimens that had been exposed for 20 weeks in the glass-covered boxes and those exposed

under alternately wet and dry conditions had been tested for stability, their bitumen was extracted with benzol, recovered by Abson's method⁶, and tested for consistency and solubility. Some of the original material was dissolved in benzol and recovered in the same manner for comparative purposes. These results are given in table 8. The high temperatures existing at times in the glass-covered exposure boxes developed residues in the cylinders which, when extracted, were much harder than the distillation residues of the original liquid asphalts and, in the case of samples 1 and 5, were semisolid.

The bitumen recovered from the cylinders exposed under alternately wet and dry conditions was much harder than the original material although, except for samples 4 and 6, it was softer than the distillation residue. Comparisons of the percentages of material insoluble in 86° B. naphtha in the bitumen from the cylinders after alternately wet and dry exposure and the percentages of insoluble matter in the distillation residues indicate that in some cases considerable alterations occurred in the structure of the bitumen exposed under these conditions.

RESULTS OF TESTS ON TOUGHNESS CYLINDERS INDICATED VARIABLE CHARACTERISTICS OF THE MATERIALS

The Page impact test was used to obtain further information on the behavior of these mixtures after exposure. This test has been used in previous studies of bituminous mixtures in the Bureau laboratory, and in a report by Reeve and Lewis⁷, it was indicated that this test offered possibilities as a means for determining in advance the relative service behavior of bituminous concretes.

The impact cylinders used in this investigation consisted of six sets of three specimens each for each mixture. The cylinders, 1 inch in diameter and 1 inch high, were prepared in the same manner as the Hubbard-Field stability cylinders. They were aged in the glass-covered boxes and one set was tested at the end of 1, 3, 5, 10, 15, and 20 weeks of exposure. The test was made at 77° F. using the Page impact machine equipped with a 500-gram hammer and a 110-gram plunger instead of the 500-gram hammer and 1-kilogram plunger used in the work of Reeve and Lewis⁷ and the 2-kilogram hammer and 1-kilogram plunger normally used in testing rock. Even with these smaller weights some of the specimens could not support the plunger and the impact value was reported as zero.

The results of these tests, given in table 9, show that cylinders containing samples 2 and 6 developed little resistance to impact. Cylinders containing samples 1 and 3 developed maximum toughnesses of 13 and 9, respectively. The cylinders containing samples 4 and 5 first showed an increase in toughness, and then, as the time of exposure increased, lost in toughness. After 20 weeks of exposure under glass the cylinders of sample 1 had the highest stability and the highest toughness.

The cylinders of sample 5, although having three and one-half times greater stability than cylinders of sample 2, had the same resistance to impact. Although the stabilities of the cylinders of samples 4 and 5 showed no great change as the time of exposure increased, the gradual loss in toughness by the cylinders of sample 5 and the rather abrupt loss in resistance to impact by

⁶ Method and Apparatus for Recovery of Asphalt. 1933 Proceedings American Society for Testing Materials.

⁷ Toughness of Bituminous Aggregates, Journal of Agriculture Research, vol. X, no. 7, August 1917.

TABLE 9.—Results of impact tests on cylinders aged under glass

Age when tested (weeks)	Loss of bitumen by sample no.—						Height of drop at failure for sample no.—					
	1	2	3	4	5	6	1	2	3	4	5	6
	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Cm	Cm	Cm	Cm	Cm	Cm
1	11	2	6	0	7	0	0	0	0	0	0	0
3	21	1	9	1	11	0	12	0	3	3	5	0
5	22	1	11	6	13	5	12	1	7	5	4	1
10	22	0	13	—	12	—	13	2	5	10	4	2
15	23	1	16	5	14	3	13	2	9	4	3	1
20	22	0	15	4	14	3	12	2	8	5	2	1

cylinders of sample 4 undoubtedly result from changes occurring in the residual binders.

The Bureau's circular track, shown in figure 9, was used for testing the materials under weathering and traffic. This track was briefly described in the January 1934 issue of PUBLIC ROADS. It consists essentially of an annular concrete trough 12 inches deep, 18 inches wide, and 12 feet in diameter at the center line. Two full-size automobile wheels, fixed to the two ends of a rigid structural member rotated in a horizontal plane by a vertical shaft at the center of the track, provided the traffic. The load on each tire was 800 pounds. A hand-wheel adjustment made it possible to shift the path of the wheels to any position on the track surface. For compaction a speed of 4½ miles per hour was used, and for all subsequent applications of traffic a speed of 6 miles per hour was used.

The track was divided into 6 sections numbered 1 to 6, corresponding to the samples of asphaltic material. The surfaces were placed June 6, 1934, upon a sand-choked, trap-rock base on which a thin layer of sand-cement mortar had been placed to provide a smooth, somewhat porous base. The surfaces were compacted the following day by means of 1,000 wheel-trips of traffic distributed over the surface. At this time the surfaces of sections 1, 3, and 5 were well closed, smooth, and uniform in appearance. The surface of section 4, although slightly drier and more open, was also smooth and uniform in appearance. The surfaces of sections 2 and 6 were smooth but somewhat nonuniform in color and had a greasy, noncohesive appearance.

MIXTURES ON CIRCULAR TRACK REMAINED IN GOOD CONDITION DURING EXPOSURE TO WEATHER AND TRAFFIC

The sections were subjected to traffic only 1 day each week, when 2,000 wheel passages of traffic were applied, distributed over the surface. The track was covered at night and during inclement weather by a portable shed. Traffic was applied weekly until October 1, 1934, when testing was suspended for the winter. During this period the maximum daily temperature in the surface mixtures ranged from 82° to 144° F. with an average daily maximum of 114° F.

In the very early stages of the test, section 1 developed quite a tough, well-bonded crust which gradually increased in hardness. Surface cracking developed in this section during the sixth week after construction. On hot days some subsurface movement of the mixture could be detected under traffic. The condition of section 1, except for the cracks that developed, remained good throughout the test.

The surface of section 2 was picked up by the tires during the first weekly application of traffic. This condition necessitated the use of canvas covers during the traffic runs up to and including the ninth week,

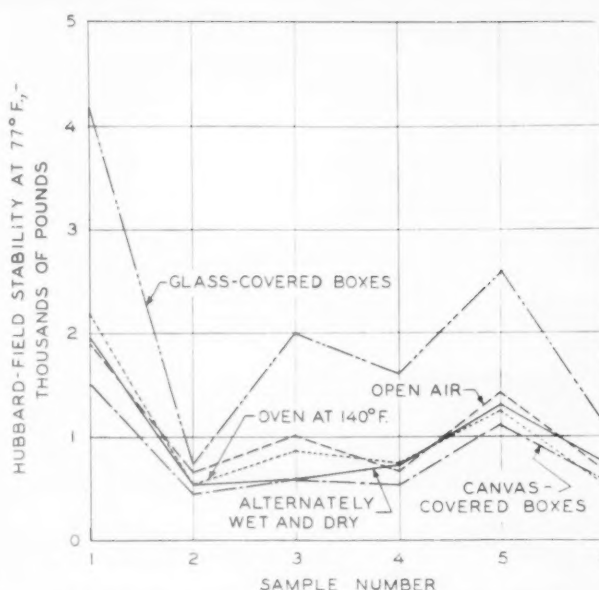


FIGURE 8.—FINAL STABILITIES OF HUBBARD-FIELD CYLINDERS AFTER VARIOUS METHODS OF AGING. ALL CYLINDERS TESTED AFTER AGING FOR 20 WEEKS EXCEPT THOSE AGED IN OVEN WHICH WERE TESTED AFTER 5 WEEKS.

after which time the surface did not pick up under traffic. Slight cracking developed in the sixth week. Some raveling was noticeable until the twelfth week when virtually all raveling ceased, the surface remaining well cemented thereafter.

Section 3 raveled slightly during the first weekly application of traffic. After that no further raveling was noted except for one small area which raveled during the seventh weekly traffic run and healed during the eighth traffic run. Hair cracks developed during the fourth week. Considerable subsurface movement under traffic was noted from the twelfth week to the end of the summer but the general appearance of the section continued to be good.

Section 4 remained in good condition throughout the summer. Hair cracks developed during the fifth week and were noticeable until the twelfth week when they became cemented and did not again develop. Section 5 also maintained a good appearance although the cracks that developed during the fourth week remained unhealed to the end of the summer.

Section 6 developed a surface similar to section 2 and canvas covers were used on it during traffic up to and including the ninth weekly traffic run. The surface was then slightly greasy and still raveled to some extent. This raveling continued with slight moderation until the end of the summer.

As the appearance of the sections at the end of the summer of 1934 did not indicate that there had been any failures caused by weathering of the asphaltic binders, the surfaces were again exposed beginning on May 27, 1935, and again subjected to 2,000 wheel passages weekly until September 27, 1935. During this period the maximum daily air temperature varied from 64° to 98° F. with an average daily maximum of 86° F.; the maximum daily temperature of the mixtures one-half inch below the surface varied from 65° to 151° F. with an average daily maximum of 126° F.; and at 1½ inches below the surface the maximum daily temperature varied from 64° to 142° F. with an average daily maximum of 117° F.



FIGURE 9.—OUTDOOR CIRCULAR TRACK USED IN THE WEATHERING TESTS.

Since the surfaces had become fairly well bonded, the shed that had been used to protect the track at night and on rainy days was removed on the first of July for the balance of the test. No noticeable changes occurred in the appearance of the surfaces from week to week and on September 27, 1935, after 70,000 wheel-passages, the appearance and condition of the surfaces were good, as shown in figure 10.

The track sections shown in figure 10 are briefly described as follows:

Section 1: Gray, hard, and well-bonded, with open alligator cracks; soft and yielding underneath.

Section 2: Black and pliable with a thin, easily broken surface skin having very indistinct cracks; soft and yielding underneath; asphalt seeped through the hard cracks slightly under traffic.

Section 3: Grayish black, well-bonded and fairly tough with slight alligator cracks; soft and yielding underneath.

Section 4: Grayish black, firm and well-bonded with almost indistinguishable hair cracks; firm underneath.

Section 5: Grayish black, firm and well-bonded with indistinct hair cracks; a black hairline of asphalt along each crack showed a tendency to heal by seepage and hardening of the asphalt.

Section 6: Black and greasy; firm with no cracks but not well cemented; surface raveled if broken slightly; firm underneath.

TRAFFIC ON ALTERNATELY WET AND DRY TRACK CAUSED FAILURE OF CERTAIN MIXTURES

As the asphaltic materials had shown considerable variations in characteristics and behavior, as measured

by the results of other tests and the track sections containing them had shown no great variations in behavior under the traffic test, it was decided to change the character of the traffic test. After making permeability tests, which indicated that all of the surfaces were impervious to water, traffic was applied in increments of 6,000 wheel passages daily. The surfaces of the sections were sprinkled with water 1 day during the period of traffic application; the following day traffic was applied with the surface dry. Thus the track was alternately wet 1 day and dry the next during the application of traffic.

No changes were noted in the condition of the sections until the third application of traffic on the wet track when sections 2 and 6 began to ravel, section 2 raveling the most. This raveling diminished considerably the following day when the track was dry. The asphaltic material seemed to have been stripped from the sand particles on the surface. Section 3 started to ravel on the fourth application of traffic on the wet track, although the sand displaced from the surface of section 3 appeared to carry more oil than that thrown off the surfaces of sections 2 and 6. Sections 1, 2, 3, and 6, under continued traffic, tended to shove and push over the curb. This behavior was least pronounced on section 1. After the fourth application of traffic on the alternately wet and dry track, sections 2 and 6 had both raveled so extensively that the test was discontinued although sections 4 and 5 had still shown no tendency to displace or ravel. Tests showed that all of the sections were still impermeable to water. The appearance of the surface of each section is shown in figure 11.

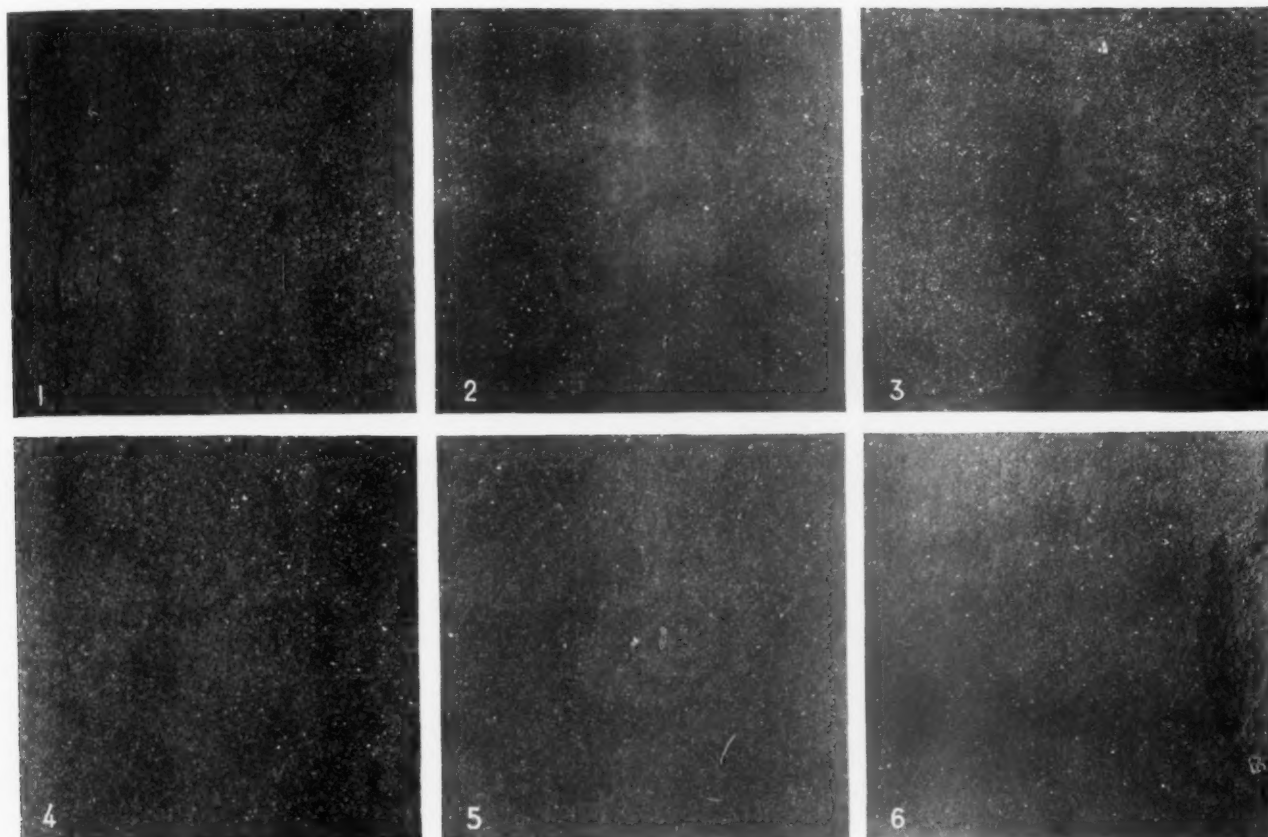


FIGURE 10.—APPEARANCES OF THE TRACK SECTIONS AFTER THE APPLICATION OF 70,000 WHEEL-PASSAGES OF TRAFFIC.

From time to time 2-inch cylinders the full depth of the surfaces were cored from the track sections and the upper inch was tested for stability at 77° F. in the Hubbard-Field machine. The holes from which the cores were taken were refilled with the previously molded cylinders. The results of these stability tests are given in table 10.

After the completion of the final traffic tests, a portion of each section was removed for extraction of the soluble asphaltic material, in the same manner as previously described, and the recovered bitumen analyzed. The results of these tests are given in table 11. Layers of the surface one-half inch thick were used for analysis. Section 1 was the only section that had an appreciable surface crust. This crust was approximately one-eighth inch thick and the bitumen therein was recovered separately, in addition to the bitumen recovered from the top ½-inch layer which included this crust. Sections 1, 2, and 3 possessed varying degrees of plasticity throughout their entire thickness, section 1 being the most plastic, followed by section 3 and then section 2, which, although greasy, was slightly plastic. Sections 4, 5, and 6 were friable and crumbly, section 6 having a very dry, somewhat greasy appearance.

Comparison of tables 7 and 10 shows that only the cores of sections 2, 4, and 6 had greater stabilities at the conclusion of the test than did the molded cylinders containing the same asphaltic binder and exposed under glass for 20 weeks. Stability is developed by an increase in the density of the mixture or by an increase in the hardness of the contained bitumen. The molded cylinders increased in stability only through an increase in the hardness of the bitumen by loss of volatile matter

TABLE 10.—Results of Hubbard-Field stability test at 77° F. on cores taken from the track sections

Date cored	Sample no.					
	1	2	3	4	5	6
June 8, 1934 (immediately after compaction).....	Lb. 350	Lb. 400	Lb. 200	Lb. 250	Lb. 225	Lb. 225
June 12, 1934 (after 1 week).....	300	250	150	250	350	250
June 26, 1934 (after 3 weeks).....	500	300	250	300	350	250
July 10, 1934 (after 5 weeks).....	600	425	400	500	575	450
Aug. 14, 1934 (after 10 weeks).....	1,125	875	650	750	950	700
Sept. 19, 1934 (after 15 weeks).....	1,525	1,250	700	1,100	950	950
May 27, 1935 (before 1935 exposure).....	1,950	1,250	975	1,250	1,075	1,125
Sept. 27, 1935 (before traffic on alternately wet and dry track).....	2,300	1,675	1,500	1,700	1,425	1,275
Dec. 9, 1935 (final tests).....	2,375	1,800	1,450	1,825	1,550	1,650

and other alterations. This increase in hardness, as previously shown, was considerable, especially by the cylinders of samples 1 and 5.

The track surfaces, on the other hand, increased in stability both from an increase in hardness of the bitumen and from increased density caused by traffic. The bitumen extracted from the surfaces was in no case as hard as the bitumen extracted from the molded cylinders exposed under glass. In no case, except the top ½-inch layer of section 1, were the extracted bitumens appreciably harder than the residues from distillation of the original materials. In the case of the sections containing samples 2, 3, 4, and 6 the extracted bitumen was of approximately the same consistency as the distillation residue. In the case of the section containing sample 1 (exclusive of the ½-inch crust), and of sample 5, the extracted bitumen was softer than the distillation residue.

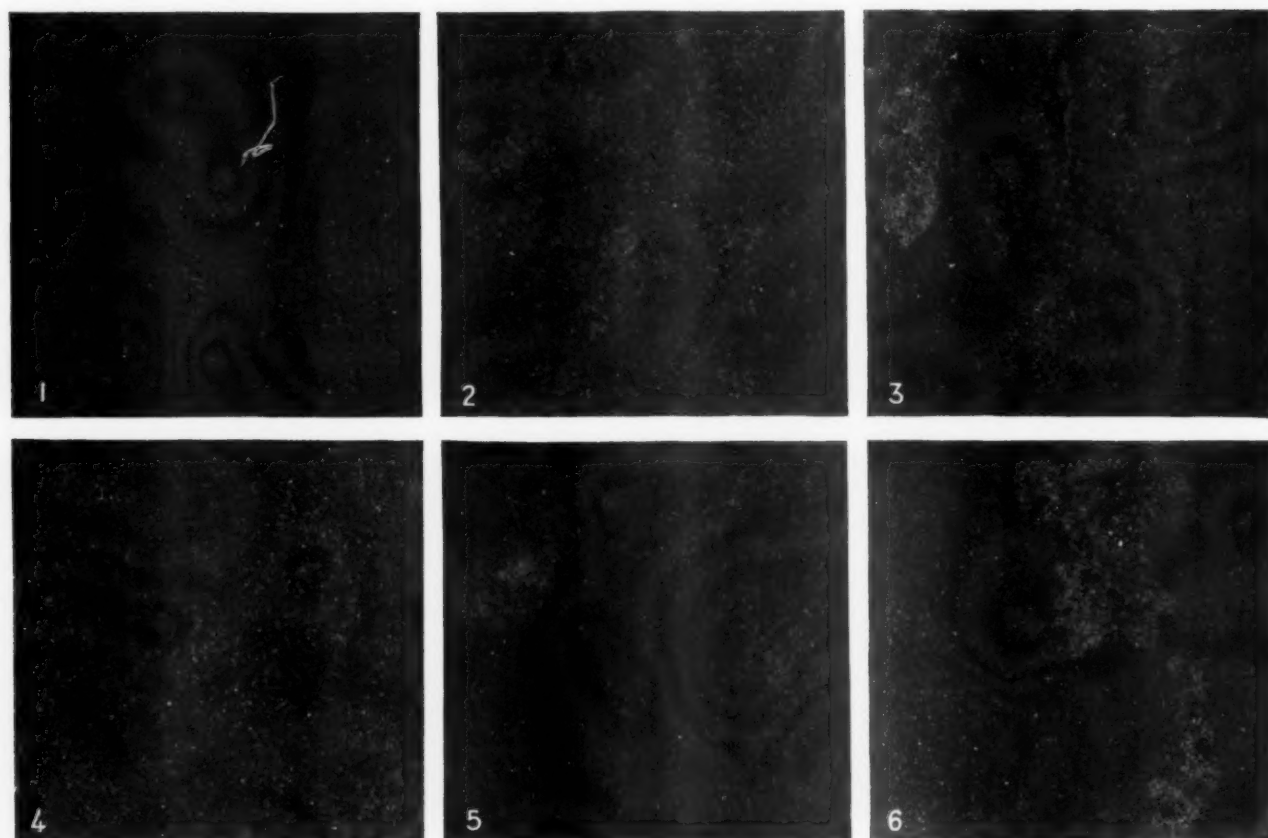


FIGURE 11.—APPEARANCES OF TRACK SECTIONS AT END OF TEST.

TABLE 11.—Results of tests on bitumen recovered from circular track sections after completion of traffic tests

Section	Asphaltic material in mixture when laid ¹	Layer	Bitumen extracted ¹	Tests on recovered bitumen			
				Float at 122° F.	Organic matter insoluble in CS ₂	Organic matter insoluble in CCl ₄	Organic matter insoluble in 86° B. naphtha
				Percent	Seconds	Percent	Percent
1	7.5	Top 1/4 inch.....	7.1	232	0.04	0.08	31.5
		Top 1/2 inch.....	7.1	80	.04	.03	25.7
		Second 1/2 inch.....	7.0	50	.06	.04	25.1
		Third 1/2 inch.....	6.7	39	.07	.03	24.6
2	7.3	Top 1/4 inch.....	7.7	36	.04	.08	8.5
		Top 1/2 inch.....	7.4	36	.08	.11	7.3
		Second 1/2 inch.....	6.9	43	.12	.10	7.6
		Third 1/2 inch.....	7.3	38	.08	.04	14.3
3	7.5	Top 1/4 inch.....	7.2	26	.21	.21	11.9
		Top 1/2 inch.....	7.2	26	.06	.04	11.1
		Second 1/2 inch.....	7.4	39	.09	1.07	18.0
		Third 1/2 inch.....	7.3	32	.14	1.01	16.9
4	8.1	Top 1/4 inch.....	8.1	25	.08	.76	16.6
		Top 1/2 inch.....	7.5	56	.08	.75	21.2
		Second 1/2 inch.....	7.5	49	.11	.88	20.5
		Third 1/2 inch.....	7.1	66	.12	.82	21.5
5	7.8	Top 1/4 inch.....	7.0	38	.27	.52	10.4
		Top 1/2 inch.....	6.9	33	.17	.25	9.6
		Second 1/2 inch.....	6.5	35	.20	.99	10.4
		Third 1/2 inch.....					

¹ Percentage by weight.

The high stabilities of the final cores from the track sections containing samples 2, 4, and 6, when compared with the low stabilities obtained on the cylinders after 20 weeks of exposure under glass (in which the asphaltic materials had hardened to a greater extent), indicate that the higher stabilities of the cores from the circular track sections must result chiefly from the increased densities that developed under the action of traffic. Although a hard outer crust was formed on the molded

specimens, no appreciable crust was formed on any of the track sections except section 1. This is shown for sections 2, 3, and 6 by the fact that, although raveling removed the surfaces to a great extent upon sections 2 and 6 and to a lesser extent on section 3 during the final application of traffic on the alternately wet and dry track, results of stability tests on the final cores taken from the track sections showed that no change in stability occurred during this period.

SUMMARY

While the purpose of this investigation was to correlate the service behavior of these selected slow-curing, liquid asphalts and road mixtures containing them with the results of the usual laboratory tests and with the results of the exposure tests, there are certain factors that must be considered in interpreting the test data already presented.

It is believed that the conditions of the circular track weathering test were not as severe as those to which mixtures of similar character would be subjected if placed as actual road surfaces for the following reasons:

1. The surfaces received lateral support from the curbs.
 2. The sections were laid on a dry, stable, nonflexible base.
 3. The traffic applied subjected the surfaces to practically no impact or mutilative forces.
 4. Comparatively light wheel loads were applied.
- The fine-graded mixtures compacted to produce a dense, tight surface so that loss of volatile matter and weathering of the asphaltic binders were greatly retarded.

The conditions of the exposure tests, especially those made on the thin films and molded specimens in the glass-covered boxes, were more severe than those that occur in the circular track test or under actual road conditions. Accordingly, the extreme differences in ultimate behavior of the track sections, which the results of the exposure tests on both thin films and molded specimens indicated might occur, did not develop within the period these sections were under test.

The great potential differences in hardening properties of the materials investigated are shown by the results of the laboratory tests as well as by the exposure test results. It is clearly indicated that the distillation requirements for SC-2 material and the consistency requirements for the residue from distillation are too wide to permit selection of liquid asphalts with comparable hardening properties. The behavior of the track section containing sample 1, which immediately developed a hard surface crust, and the slow development of a cohesive surface in the sections containing samples 2, 3, and 6, show the extremes in behavior that may occur.

While the routine laboratory tests indicated that there should be little difference in the road behavior of samples 2, 3, 4, and 6, the behavior of the track sections containing these products definitely show that there are decided differences initially and after weathering in the inherent binding and cementing qualities of these materials that are not indicated by those laboratory tests generally used to determine the conformity to specifications. The raveling that occurred in varying degrees in sections 2, 3, and 6, and the inability of these three sections to resist abrasion under traffic on the alternately wet and dry track, in contrast to the behavior of the section containing sample 4, indicate that the true cementing or binding properties of these materials are not shown by the laboratory tests on the original materials or by stability tests on the mixtures either before or after weathering.

The blended material, sample 6, did not, under the laboratory tests required by the specification for SC-2 material, show any indication of being an unstable blend. Its instability was indicated by the asphaltic residue test run at standard temperature and was definitely shown in the exposure tests and in the behavior of the track section containing this material. It is believed that this material would prove unsatisfactory as a binder in surfacing roads.

Because of the slowness of the sections containing materials 2 and 3 to resist raveling and their inability

after considerable aging to resist the scouring action of traffic when wet, it is believed that materials 2 and 3 would not prove entirely satisfactory as binders in wearing surfaces, particularly when used with fine aggregate similar to that used in this investigation.

Materials 1, 4, and 5 produced mixtures that immediately possessed good resistance to the abrasive action of traffic and were not disturbed during the final application of traffic on the alternately wet and dry track. In sections containing materials 1 and 5 some loss of volatile matter and the resultant hardening of the binder might have been responsible for their behavior. The results of tests on sample 4 and mixtures containing it indicate that the loss of volatile matter in the asphaltic material was far too small to account for the early and subsequent behavior of this section.

The relative merits of materials 1, 4, and 5 as binders in this type of construction were not definitely indicated by these tests. The development of cracks in the surface of section 1 could probably have been avoided by additional manipulation of the mixture before spreading.

The more plastic condition of the bituminous mixture in section 1 at the end of the test, in spite of the cracked surface crust, together with the high toughness developed and retained by the cylinders containing sample 1, indicate that this sample is of more durable character than samples 4 and 5 for the following reasons:

1. Sections containing samples 4 and 5 were in a friable condition when disturbed at the end of the test.
2. Impact cylinders containing samples 4 and 5 lost toughness on continued exposure.
3. There was high carbonization in the thin-film exposure residues of samples 4 and 5.

TABLE SHOWING STATUS OF PUBLIC WORKS HIGHWAY CONSTRUCTION OMITTED FROM THIS ISSUE

The table showing the current status of Public Works highway construction has been omitted from this issue. This table will appear in future issues only as space is available but at intervals not exceeding 3 months.

On June 30 Public Works highway funds were involved in 286.8 miles under construction, 117.9 miles were approved for construction and \$4,570,020 remained available for new projects.

Copies of the table showing the status by States may be obtained upon application to the Bureau.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF JUNE 30, 1937

STATE	AFFORTMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			Miles	BALANCE OF FUND FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles		
Alabama	\$ 7,872,980	\$ 51,600	\$ 25,800	9.0	\$ 1,354,601	\$ 677,300	58.5	\$ 4,029,960	\$ 2,014,975	177.3	177.3	\$ 5,154,905
Arizona	5,394,661	2,165,515	2,110,123	151.0	1,332,431	989,780	41.6	697,951	329,004	17.7	17.7	1,965,754
Arkansas	6,463,651	65,174	65,029	2.0	3,377,503	3,573,161	212.6	281,712	280,214	36.3	36.3	2,545,277
California	14,766,891	3,679,392	5,472,422	269.4	7,815,071	4,243,859	184.4	2,651,589	1,419,031	53.6	53.6	3,231,610
Colorado	6,911,198	4,742,008	2,547,978	189.8	3,496,091	1,945,322	119.5	162,993	86,142	3.3	3.3	2,331,756
Connecticut	2,368,339	770,265	383,414	14.2	745,158	370,176	8.7	194,520	89,623	1.3	1.3	1,545,126
Delaware	1,443,750	745,375	360,062	33.0	415,500	207,664	12.3	340,718	168,337	22.0	22.0	1,107,687
Florida	5,080,323	1,240,059	609,422	40.2	1,642,722	821,356	55.9	1,084,970	542,465	11.6	11.6	3,047,060
Georgia	2,569,722	2,284,121	1,100,700	139.6	2,763,142	1,381,556	138.8	2,387,926	1,193,963	98.3	98.3	5,893,503
Idaho	4,635,991	2,897,006	1,670,144	270.0	1,815,329	1,086,636	117.5	573,983	342,227	42.6	42.6	1,536,983
Illinois	15,564,720	9,503,185	4,715,011	145.2	2,149,527	4,584,998	292.5	5,816,572	2,905,428	193.3	193.3	3,419,204
Indiana	9,333,269	6,108,500	2,987,215	197.3	6,077,247	3,038,563	185.7	2,084,584	1,042,232	73.1	73.1	2,265,198
Iowa	9,757,950	7,436,661	3,663,599	506.2	5,525,075	2,443,447	168.3	1,745,919	845,595	46.9	46.9	2,805,349
Kansas	10,005,211	5,066,220	2,528,671	87.5	6,156,702	3,051,745	248.6	1,881,796	940,892	117.2	117.2	3,483,904
Kentucky	6,961,271	2,921,522	1,420,361	173.4	2,928,837	1,414,419	63.5	1,983,288	991,754	89.3	89.3	3,134,737
Louisiana	5,387,420	2,202,443	1,095,119	81.6	1,208,767	604,080	28.9	9,482,705	1,222,235	46.0	46.0	2,465,995
Maine	3,299,467	2,075,544	1,021,149	65.7	1,622,446	811,423	44.1	715,845	357,922	20.3	20.3	1,109,373
Maryland	3,094,808	333,935	166,968	3.1	1,620,106	810,920	23.8	497,318	246,659	7.4	7.4	2,036,129
Massachusetts	5,255,300	9,944,424	4,867,663	352.3	4,834,456	2,217,228	20.3	556,904	278,451	2.3	2.3	2,592,653
Michigan	11,562,296	9,109,039	4,322,826	611.7	6,956,412	3,318,206	166.0	2,990,351	1,494,550	70.4	70.4	1,881,877
Minnesota	10,344,465	4,640	2,320	498.1	2,780,210	1,350,050	170.8	712,385	293,314	28.9	28.9	3,895,364
Mississippi	11,479,090	5,447,831	2,710,192	418.8	7,865,846	3,907,413	337.0	2,938,580	1,468,680	134.8	134.8	3,774,294
Missouri	7,744,061	4,297,008	1,691,588	224.8	3,368,773	1,888,515	236.4	4,533,708	1,850,427	211.7	211.7	3,011,058
Montana	7,809,353	3,393,372	1,452,470	272.9	4,379,290	2,209,007	477.5	2,157,978	1,047,971	152.0	152.0	2,759,860
Nebraska	4,821,864	1,709,532	864,727	25.2	1,856,599	1,597,569	76.1	798,515	692,427	41.8	41.8	2,860,767
New Hampshire	1,843,750	864,727	411,300	25.2	1,800,047	89,661	1.9	388,810	191,502	5.9	5.9	1,079,398
New Jersey	5,094,295	2,709,559	1,336,457	39.3	2,055,959	950,624	20.3	832,890	253,405	1.9	1.9	2,513,349
New Mexico	6,030,708	4,187,401	2,567,325	345.7	2,596,381	1,225,658	130.4	1,151,018	701,756	103.9	103.9	1,835,969
New York	18,565,567	9,924,332	4,836,719	190.0	17,708,946	8,200,934	250.0	4,523,240	2,256,070	68.7	68.7	3,821,785
North Carolina	8,877,837	3,662,221	1,827,476	396.6	5,315,155	2,533,877	333.0	1,576,451	717,845	61.5	61.5	3,798,638
North Dakota	5,914,683	359,450	192,450	4.4	960,610	940,100	171.4	838,262	834,262	128.9	128.9	3,943,871
Ohio	13,771,648	3,449,614	1,708,688	55.2	8,038,411	3,919,692	84.6	2,507,660	1,253,830	31.1	31.1	6,889,338
Oklahoma	8,880,547	4,237,711	2,210,200	156.7	2,702,586	1,417,840	99.0	2,572,827	1,331,048	106.9	106.9	3,921,459
Oregon	6,182,079	3,205,387	1,937,169	119.5	4,334,036	2,553,062	155.3	528,236	302,243	30.3	30.3	1,389,605
Pennsylvania	16,129,804	6,963,856	3,432,354	117.5	11,384,046	5,679,999	160.6	2,882,997	1,437,722	42.0	42.0	5,579,729
Rhode Island	1,843,750	284,827	139,343	4.0	1,034,356	517,468	11.9	583,590	290,484	7.4	7.4	896,455
South Carolina	5,103,525	561,512	286,900	53.8	5,341,129	2,225,058	328.3	901,891	332,135	42.9	42.9	2,899,432
South Dakota	6,162,747	1,400,542	785,366	190.3	1,528,066	857,554	144.2	772,196	430,026	96.7	96.7	4,088,801
Tennessee	7,949,360	2,877,307	1,433,351	120.4	2,085,722	1,042,761	72.0	436,740	218,370	16.6	16.6	5,254,798
Texas	23,506,411	14,504,926	7,206,201	858.1	13,254,182	6,607,046	636.8	1,486,634	742,618	72.6	72.6	8,950,567
Utah	4,274,740	2,412,545	1,688,989	159.7	1,033,133	744,271	92.2	434,570	295,290	42.8	42.8	1,546,191
Vermont	1,843,750	1,304,281	637,062	63.0	1,149,866	525,391	32.9	693,611	285,336	16.1	16.1	395,960
Virginia	6,887,569	4,087,150	2,060,703	184.2	3,020,189	1,451,896	106.7	904,854	462,127	26.5	26.5	2,922,542
Washington	5,307,615	4,795,936	2,482,160	181.6	1,877,590	984,301	63.4	1,550,337	806,798	28.8	28.8	1,634,336
West Virginia	4,107,201	863,018	431,486	42.3	1,067,993	533,940	26.6	1,379,037	684,773	40.5	40.5	2,457,002
Wisconsin	9,197,957	4,801,159	2,334,736	153.7	6,783,571	2,990,036	204.0	3,429,610	1,522,600	80.5	80.5	2,350,186
Wyoming	4,722,322	3,619,047	2,170,902	411.9	2,802,393	1,723,511	280.7	377,620	222,591	42.2	42.2	505,318
District of Columbia	1,843,750	29,953	14,542	.8	855,062	420,545	17.2	371,350	182,060	5.4	5.4	1,226,583
Hawaii	625,000	175,901,272	91,397,673	9,444.3	191,143,820	98,785,827	7,211.6	83,962,270	38,683,379	2,852.9	2,852.9	625,000
Porto Rico	368,750,000											139,883,121

1/ APPORTIONMENTS FOR FISCAL YEARS 1936 TO 1938 INCLUSIVE.

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JUNE 30, 1937

STATE	APPORTIONMENT			COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
	Estimated Total Cost	Work Program Fund	Miles	Estimated Total Cost	Work Program Fund	Miles	Estimated Total Cost	Work Program Fund	Miles	Estimated Total Cost	Work Program Fund	Miles	
Alabama	\$ 4,151,115	\$ 3,363,985	111.5	\$ 690,450	\$ 690,450	26.8	\$ 690,450	\$ 690,450		\$ 16,282	\$ 15,714	1.2	\$ 130,810
Arizona	2,569,841	3,007,951	188.6	142,121	71,615	7.3	142,121	71,615					80,678
Arkansas	3,352,061	2,829,570	317.0	466,189	465,015	42.1	466,189	465,015					41,761
California	7,747,928	6,348,604	238.2	1,596,052	1,393,180	25.7	1,596,052	1,393,180					6,144
Colorado	3,395,263	1,859,718	99.1	89,597	89,596	6.0	89,597	89,596					1,472,138
Connecticut	1,418,709	641,101	4.7	590,332	516,680	15.7	590,332	516,680					50,208
Delaware	900,310	2,048,149	80.7	2,014,532	247,538	17.7	2,014,532	247,538					43,436
Florida	4,988,967	949,466	54.2	939,519	528,731	18.3	939,519	528,731					53,881
Georgia	2,222,747	2,241,521	185.3	43,487	43,487	77.3	43,487	43,487					1,366,909
Idaho	8,694,009	7,834,755	445.1	869,714	869,636	26.1	869,714	869,636					22,169
Illinois	4,941,255	3,293,935	136.0	1,849,453	1,849,453	96.8	1,849,453	1,849,453					118,672
Indiana	4,991,664	3,997,213	451.1	1,222,895	1,186,177	76.5	1,222,895	1,186,177					6,745
Iowa	4,994,975	4,318,679	304.8	689,173	647,001	31.0	689,173	647,001					1,449
Kentucky	3,726,271	3,047,002	336.0	2,936,633	2,936,633	336.0	2,936,633	2,936,633					27,476
Louisiana	2,890,429	1,869,154	129.8	1,867,890	1,867,890	129.8	1,867,890	1,867,890					374,460
Maryland	1,676,799	1,317,692	61.2	1,303,342	1,303,342	61.2	1,303,342	1,303,342					71,525
Massachusetts	1,726,738	475,173	17.6	469,405	469,405	17.6	469,405	469,405					22,949
Michigan	2,262,885	224,227	2.7	224,227	224,227	2.7	224,227	224,227					87,417
Minnesota	6,301,414	6,440,481	287.8	5,942,362	5,942,362	287.8	5,942,362	5,942,362					107,598
Mississippi	3,457,552	5,563,716	890.5	4,681,207	4,681,207	890.5	4,681,207	4,681,207					107,598
Missouri	6,012,652	2,457,278	176.1	2,453,460	2,453,460	176.1	2,453,460	2,453,460					107,598
Montana	3,676,416	3,252,638	195.1	4,453,266	4,453,266	195.1	4,453,266	4,453,266					107,598
Nevada	3,670,739	3,075,739	334.0	2,917,697	2,917,697	334.0	2,917,697	2,917,697					107,598
New Hampshire	942,225	2,217,596	104.6	2,156,630	2,156,630	104.6	2,156,630	2,156,630					107,598
New Jersey	3,125,805	913,747	26.7	913,747	913,747	26.7	913,747	913,747					107,598
New Mexico	2,671,397	2,314,990	16.2	2,314,990	2,314,990	16.2	2,314,990	2,314,990					107,598
New York	11,046,377	9,721,035	179.9	9,721,035	9,721,035	179.9	9,721,035	9,721,035					107,598
North Carolina	4,720,173	3,063,110	217.1	3,063,110	3,063,110	217.1	3,063,110	3,063,110					107,598
North Dakota	2,867,245	2,123,281	316.1	2,099,972	2,099,972	316.1	2,099,972	2,099,972					107,598
Ohio	7,670,815	3,665,395	153.4	3,665,395	3,665,395	153.4	3,665,395	3,665,395					107,598
Oklahoma	4,580,670	3,796,397	359.9	3,796,397	3,796,397	359.9	3,796,397	3,796,397					107,598
Oregon	3,038,642	2,074,834	154.6	2,074,834	2,074,834	154.6	2,074,834	2,074,834					107,598
Pennsylvania	9,347,797	2,176,072	104.3	2,176,072	2,176,072	104.3	2,176,072	2,176,072					107,598
Rhode Island	989,808	1,078,417	18.8	989,808	989,808	18.8	989,808	989,808					107,598
South Carolina	2,702,012	1,775,334	187.1	1,775,334	1,775,334	187.1	1,775,334	1,775,334					107,598
South Dakota	2,976,454	2,177,156	140.9	2,177,156	2,177,156	140.9	2,177,156	2,177,156					107,598
Tennessee	4,132,460	2,523,809	103.1	2,523,809	2,523,809	103.1	2,523,809	2,523,809					107,598
Texas	11,989,350	12,101,643	1,087.1	11,989,350	11,989,350	1,087.1	11,989,350	11,989,350					107,598
Utah	2,067,154	1,727,883	174.7	1,727,883	1,727,883	174.7	1,727,883	1,727,883					107,598
Vermont	924,306	986,627	21.5	986,627	986,627	21.5	986,627	986,627					107,598
Virginia	3,682,667	3,130,988	941.1	3,130,988	3,130,988	941.1	3,130,988	3,130,988					107,598
Washington	3,026,161	3,159,146	163.0	3,159,146	3,159,146	163.0	3,159,146	3,159,146					107,598
West Virginia	2,231,412	957,982	43.6	957,982	957,982	43.6	957,982	957,982					107,598
Wyoming	4,823,684	4,961,434	332.6	4,961,434	4,961,434	332.6	4,961,434	4,961,434					107,598
District of Columbia	2,219,155	2,067,737	139.9	2,067,737	2,067,737	139.9	2,067,737	2,067,737					107,598
Hawaii	949,496	950,000	8.8	950,000	950,000	8.8	950,000	950,000					107,598
TOTALS	195,000,000	146,753,846	11,266.7	139,817,552	139,817,552	11,266.7	139,817,552	139,817,552					12,535
													5,761,504

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS (AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JUNE 30, 1937

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDING FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER Grade Crossings Completed by June 30, 1937	Estimated Total Cost	Works Program Funds	NUMBER Grade Crossings Underway by June 30, 1937	Estimated Total Cost	Works Program Funds	NUMBER Grade Crossings Approved for Construction by June 30, 1937	
Alabama	\$ 4,034,617	\$ 2,769,103	\$ 2,768,839	39	\$ 1,070,215	\$ 1,070,215	9	\$ 83,900	\$ 83,900	1	\$ 111,662
Arizona	1,256,099	1,116,158	1,090,434	13	108,151	108,151	1	45,632	45,632	1	11,892
Arkansas	3,574,060	1,804,637	1,799,310	32	1,542,218	1,540,068	17	212,396	212,396	1	22,287
California	7,486,352	5,347,900	5,228,650	31	1,993,959	1,949,880	15	311,710	311,710	6	123
Colorado	2,631,967	1,345,381	1,292,033	22	896,658	896,658	8	101,575	101,575	2	339,301
Connecticut	1,712,584	141,699	141,699	22	875,781	894,420	6	399,190	399,190	2	316,175
Delaware	418,239	130,000	130,000	1	764,579	763,630	12	277,993	277,993	2	10,246
Florida	2,827,883	1,757,909	1,755,191	18	1,067,054	1,067,054	22	755,449	755,449	14	309,062
Georgia	4,895,949	93,077	91,585	3	621,767	621,694	7	118,693	118,693	3	2,981,861
Idaho	1,674,479	913,521	907,056	14	4,443,962	4,443,962	23	5	5	5	189,885
Illinois	10,307,184	5,693,389	5,673,397	50	3,270,149	3,270,149	20	74,590	74,590	1	21,604
Indiana	5,111,096	1,961,642	1,813,253	22	2,686,446	2,682,027	36	86,572	86,572	1	264
Iowa	5,600,679	2,964,073	2,873,798	71	2,507,940	2,435,294	14	846,980	833,388	4	36,841
Kentucky	5,246,258	2,778,697	2,774,183	44	2,021,533	1,731,501	10	928,475	928,475	10	29,406
Louisiana	3,672,387	1,083,128	1,077,733	14	1,508,423	1,506,422	14	1,131,413	1,131,413	2	228,428
Maine	3,213,467	550,142	550,142	7	295,326	294,735	5	306,173	306,173	2	24,288
Maryland	1,426,861	850,767	849,338	15	513,978	513,978	3	980,004	947,536	4	337,323
Massachusetts	2,061,751	352,915	352,915	3	2,186,644	2,183,064	14	739,651	739,651	3	56,490
Michigan	4,210,833	1,231,713	1,231,628	10	2,267,927	2,197,458	15	43,500	43,500	1	113
Minnesota	6,765,197	4,612,994	4,524,126	38	1,641,889	1,617,990	15	57,010	57,010	11	4,560
Mississippi	5,395,141	3,789,003	3,715,881	70	1,466,531	1,466,531	22	89,800	89,800	13	478,794
Missouri	2,241,475	1,206,553	1,206,389	33	1,466,531	1,466,531	22	1,650	1,650	1	28,585
Montana	6,142,153	823,709	822,860	15	5,485,281	5,289,037	34	198,775	145,096	1	153
Nebraska	2,122,327	2,579,716	2,458,111	36	1,18,967	118,967	1	93,477	93,477	4	120,345
Nevada	3,556,441	1,934,181	1,909,203	67	1,433,416	1,433,416	15	3,630	3,630	5	7,561
New Hampshire	887,860	685,420	682,637	7	395,145	395,145	5	68,825	68,825	1	16,833
New Jersey	822,484	341,748	341,748	3	2,421,099	2,410,054	14	743,310	660,515	3	5,367
New Mexico	3,983,826	893,256	893,256	7	673,090	670,400	5	56,505	56,505	1	177,683
New York	1,725,286	1,039,545	1,038,317	13	8,351,500	8,136,700	25	94,000	94,000	1	812,335
North Carolina	13,577,189	5,228,530	5,168,806	22	2,032,307	2,012,181	23	54,950	54,950	1	140,985
North Dakota	4,623,958	1,844,493	1,844,493	25	1,465,516	1,464,516	25	340,900	340,900	14	18,010
Ohio	3,207,473	1,404,631	1,402,057	26	5,980,236	5,748,289	39	1,835,000	1,835,000	9	5,693
Oklahoma	8,439,897	481,176	415,684	3	947,328	947,328	12	1,323,663	1,323,663	9	102,505
Oregon	5,004,711	2,724,357	2,715,710	44	1,170,816	1,089,215	6	51,387	51,387	15	2,479
Pennsylvania	11,463,613	2,350,848	2,104,071	38	8,344,686	7,718,326	39	1,554,956	1,554,956	1	503,145
Rhode Island	699,691	649,511	649,511	4	36,240	36,240	1	12,567	12,567	4	5,356
South Carolina	3,059,966	1,114,398	1,103,681	22	1,159,733	1,151,601	21	393,328	301,528	28	357,581
South Dakota	3,249,086	1,132,083	1,131,466	28	2,546,660	2,546,660	23	232,510	232,510	2	383,402
Tennessee	3,931,979	775,083	767,048	15	2,644,561	2,644,561	26	411,577	411,577	1	14,444
Texas	10,655,982	7,427,566	7,416,645	104	1,874,321	1,874,321	14	754,414	746,692	6	82,903
Utah	1,230,783	343,803	342,397	3	2,644,561	2,644,561	26	411,577	411,577	1	10,476
Vermont	759,857	497,840	486,213	7	1,271,633	1,271,633	3	695,138	695,138	8	81,492
Virginia	3,774,287	2,053,045	1,943,175	35	1,001,516	1,001,516	10	23,265	23,265	5	14
Washington	3,095,041	2,231,646	2,196,919	20	883,510	883,085	3	78,153	78,153	1	14,000
West Virginia	2,677,937	79,454	79,454	1	1,821,853	1,821,853	17	746,692	746,692	6	82,903
Wisconsin	5,022,683	2,579,025	2,544,335	27	2,465,436	2,465,436	10	23,265	23,265	5	14
Wyoming	1,360,841	665,281	665,173	9	617,516	617,516	4	78,153	78,153	1	14,000
Dist. of Columbia	410,804	425,564	396,804	3	351,976	283,314	3				
Hawaii	453,703	170,404	170,404	2							
TOTALS	196,000,000	86,354,351	84,836,616	1152	90,217,477	87,223,677	698	16,345,864	15,210,179	136	8,729,528